NASA Technical Memorandum 81830

GROUND CLOUD HYDROGEN CHLORIDE MEASUREMENTS FROM THREE TITAN LAUNCHES AT THE KENNEDY SPACE CENTER DURING 1978 AND 1979

DANIEL I. SEBACHER, ROBERT B. LEE, III
AND JOSEPH J. MATHIS

JUNE 1980

NASA
National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

GROUND CLOUD HYDROGEN CHLORIDE MEASUREMENTS FROM THREE TITAN LAUNCHES AT THE KENNEDY SPACE CENTER DURING 1978 and 1979

Daniel I. Sebacher, Robert B. Lee III, and Joseph J. Mathis
Langley Research Center

SUMMARY

Total hydrogen chloride and gaseous hydrogen chloride concentrations were measured in the exhaust cloud produced at three Titan III launches at the Kennedy Space Center in March 1978, December 1978, and November 1979. The primary purpose of this study was to determine the degree of hydrogen chloride partitioning in a solid rocket exhaust cloud between gaseous hydrogen chloride and hydrochloric acid aerosol as the cloud is diluted with humid ambient air. Moderately low relative humidity conditions were present during a daytime launch on March 25, 1978, and high relative humidity conditions were present during a nightime launch on December 13, 1978.

Total and gaseous hydrogen chloride concentrations and meteorological data, as a function of time after launch, are presented in this report. The measurements show that hydrogen chloride is present in both the gaseous and aerosol phase in the exhaust cloud. Total HCℓ concentrations ranged from 18 parts per million by volume (ppm) several minutes after launch down to 1 ppm after the cloud stabilization period, depending on the meteorological conditions. Gaseous HCℓ concentrations ranged from 2 to 3 ppm several minutes after launch to less than 1 ppm after cloud stabilization. These measured concentrations indicated significant HCℓ aerosol formation.

INTRODUCTION

Solid propellant rocket motor (SRM) launches produce an exhaust cloud containing hydrogen chloride (HCℓ) along with other pollutants which are rapidly diluted with the surrounding moist ambient air. The environmental effects of HCℓ in SRM exhaust clouds are being studied by the NASA Langley Research Center under the launch effluent monitoring program, using Titan III launches, to prepare for the environmental impact of future Space Shuttle flights. The object of the LVE program is to assess the accuracy of analytical models, under development, which will predict the dispersion of SRM exhaust effluents from current and future launch vehicles. The purpose of this study was to measure the partitioning of HCℓ in a Titan II exhaust cloud between hydrochloric acid aerosol and gaseous HCℓ as the cloud is diluted with ambient air. Partitioning was determined by measuring the HCℓ concentration with an in-house developed HCℓ gas filter correlation detector (GFC), which measures only gaseous HCℓ, and simultaneously with a commercial total HCℓ detector (Geomet). These measurements will be used for verification of modeling schemes being developed for the exhaust cloud studies.

The NASA has monitored a number of previous Titan III launches which included ground-level measurements of the exhaust effluents settling to the Earth's surface as well as airborne measurements within the stabilized cloud. This program had a dual purpose of developing the measuring techniques and operational procedures for Shuttle launches, as well as accumulating data to be used to evaluate the environmental impact of future launch activities. Details of the LVE program can be found in references 1 to 10.

This paper will summarize the airborne measurements obtained during the March 25, 1978 launch at 1:09 p.m. e.s.t., during the December 13, 1978 launch at 7:40 p.m. e.s.t., and during the November 21, 1979 launch at 9:08 p.m. e.s.t. Meteorological information has been included to make the data set as complete as possible. A detailed analysis of parts of the March 1978 launch data has been published and can be found in reference 11. The format of this paper is one of detailed data presentation of all three launches.

SYMBOLS

C	temperature, centigrade
Geomet	total HCℓ detector (gaseous plus aerosols)
GFC	gas filter correlator (gaseous HCℓ detector)
LVE	launch vehicle effluents
ppm	parts per million by volume
SRM	solid rocket motor
T	launch time

DATA RESULTS

Airborne Measurement Program

A twin-engine light aircraft, used as the sampling platform, was maintained in a holding pattern west of the launch site until T + 1 minute. Airborne sampling passes were then executed through the center of the cloud in both the downwind and crosswind directions every 3 to 5 minutes using a continuous figure "8" pattern. The cloud center was determined visually by the flight crew.

The sampling aircraft (ref. 8) was equipped to monitor gaseous HCℓ (GFC) and total HCℓ (Geomet). In addition, routine flight parameters (altitude, heading, and air speed) were recorded. A complete documentation of the GFC may be found in reference 12, and a detailed description of the Geomet is given in reference 13. Installation of the sampling system aboard the aircraft is illustrated in figure 1. Effluent air samples are taken into the aircraft through specially designed sampling probes located in the nose of the aircraft. These probes extended forward of the flow-field disturbance created by the aircraft nose, thus collecting undisturbed, free-stream sampling air.

Exhaust Cloud Stabilization

The launching of a Titan III produces a plume of hot exhaust effluents which mix with the moist ambient air and rise because of buoyancy forces. Only the SRM boosters contribute effluents to the gound cloud since the liquid propellant is ignited at a higher altitude. After rising for 4 to 8 minutes after launch, the exhaust cloud usually stabilizes at an altitude of 1 to 2 km depending on the meteorological conditions, and then drifts with the prevailing winds.

The March 1978 exhaust cloud stabilized at about 1.5 km and data were obtained starting at 7 minutes and ending at 109 minutes after launch using the airborne sampling system. Cloud altitude stabilization obtained by aircraft penetration is shown in figure 2. Penetration times were taken when the HCℓ sensors indicated that the aircraft first entered the exhaust cloud. Figure 2 was plotted from the data of table I which lists the sampling altitude, aircraft heading, and cloud penetration time for each sampling pass.

The December 1978 exhaust cloud stabilized at about 1.22 km and data were obtained starting at 3 minutes and ending at 40 minutes after launch. Cloud altitude stabilization of this launch is shown in figure 3, and the tabulated sampling parameters are given in table III. The November 1979 exhaust cloud stabilized at about 1.56 km, and data were obtained at 4 minutes and ending at 23 minutes after launch. Cloud altitude stabilization of the November 1979 launch is shown in figure 4, and the tabulated sampling parameters are given in table III.

Meteorology

Meteorological conditions obtained from rawinsonde measurements taken near the launch time are presented in figure 5 for the March 1978 launch, in figure 6 for the December 1978 launch, and in figure 7 for the November 1979 launch. Relative humidity and temperature of the ambient air are the dominant meteorological parameters which determine the amount of HCℓ aerosol formation in the exhaust cloud. Since all three clouds stabilized below 2 km, the vertical profiles of temperature, wind direction, wind speed, and relative humidity were terminated at this altitude. All three launches were carried out at launch complex 41.

Airborne HCℓ Measurements

March 1978 launch.- In-cloud concentrations of total HCℓ (Geomet) and gaseous HCℓ (GFC) measured during each sampling pass are shown in figure 8. Zero time for each of these plots was set at launch time which was 1:09 p.m., e.s.t. for the March launch. Clear weather conditions occurred during this daytime launch, allowing extensive sampling for up to 109 minutes after launch. Thirty sampling passes were completed. For this launch, maximum

observed total HCℓ concentration was about 18 ppm, having occurred during pass 4. The total HCℓ concentration rapidly decayed after this maximum to a value of about 2 ppm during pass 30 (6498 seconds after launch). Maximum observed gaseous HCℓ concentration was about 2.5 ppm, occurring during passes 5 and 6. The gaseous HCℓ concentration also rapidly decayed to a value of about 0.6 ppm during pass 30. Peak values of HCℓ concentration for each pass were evaluated from figure 8 and were tabulated in table IV. These values indicate an exponential decay of both total and gaseous HCℓ concentration with time.

December 1978 launch.- In-cloud concentration of total HCℓ (Geomet), gaseous HCℓ (GFC), relative humidity, and temperature measured during each sampling pass of the December launch are shown in figure 9. Relative humidity and temperature measurements were added to the airborne measurement program at this time because of difficulty in correlating the HCℓ partitioning data to the rawinsonde meteorology measurements (references 11 and 12). Broken cloud conditions occurring during this nighttime launch, allowed for only 11 passes before the exhaust cloud was lost. For this launch, maximum observed total HCℓ concentration was about 9.7 ppm during pass 2, and maximum gaseous HCℓ was about 1.6 ppm during pass 1. Both total and gaseous HCℓ concentration again rapidly decreased. The peak values obtained from figure 9 are tabulated in table V.

November 1979 launch.- In-cloud concentrations of total HCℓ (Geomet), gaseous HCℓ (GFC), relative humidity, and temperature measured during each sampling pass of the November 1979 launch are shown in figure 10. Overcast conditions occurring during this nighttime launch resulted in only eight passes being completed before the exhaust cloud was lost. For this launch, maximum observed total HCℓ concentration was about 3.8 ppm and maximum gaseous HCℓ was about 0.4 ppm, both measured during pass 1. Total HCℓ and gaseous HCℓ concentrations again rapidly decreased with time, but the values measured during this launch were much lower than those measured at corresponding times after launch when compared to the other two launches. Two passes were made under the cloud as indicated in table III to determine if any rainout of HCℓ was occurring under these meteorological conditions. Low-level concentrations of HCℓ were measured for each of the passes executed under the cloud.

CONCLUDING REMARKS

The data presented in this report have verified that HCℓ can exist in both the gaseous state and the aerosol state in a SRM exhaust cloud. No attempt was made to interpret the HCℓ partitioning measurements in this paper. The characteristics of the exhaust clouds of these launches were typical of other launches in that the clouds stabilized below 2 km and then dissipated under moderate meteorological conditions. The measured profiles show that the HCℓ concentrations decreased with time as expected as the cloud grew in volume when diluted with ambient air. Meteorological information has been included to make the data set compatible with the data gathered during earlier launches.

REFERENCES

1. Gregory, Gerald L.; Hulten, William C.; and Wornom, Dewey E.: Apollo Saturn 511 Effluent Measurements From the Apollo 16 Launch Operations-An Experiment. NASA TM X-2910, 1974.

2. Gregory, Gerald L.; and Storey, Richard W. Jr.: Effluent Sampling of Titan IIIC Vehicle Exhaust. NASA TM X-3228, 1975.

3. Stewart, Roger B.; Sentell, Ronald J.; and Gregory, Gerald L.: Experimental Measurements of the Ground Cloud Effluents and Cloud Growth During the February 11, 1974, Titan-Centaur Launch at Kennedy Space Center. NASA TM X-72820, 1976.

4. Gregory, Gerald L.; Wornom, Dewey E.; Bendura, Richard J.; and Wagner, H. Scott: Hydrogen Chloride Measurements From Titan III Launches at the Air Force Eastern Test Range, Florida 1973 Through 1975. NASA TM X-72832, 1976.

5. Gomberg, Richard I.; and Stewart, Roger B.: A Computer Simulation of the Afterburning Processes Occurring Within Solid Rocket Motor Plumes in the Troposphere. NASA TN D-8303, 1976.

6. Bendura, Richard J.; and Crumbly, Kenneth H.: Ground Cloud Effluent Measurements During the May 30, 1974, Titan III Launch at the Air Force Eastern Test Range. NASA TM X-3539, 1977.

7. Stephens, J. Briscoe; and Stewart, Roger B.: Rocket Exhaust Effluents Modeling for Tropospheric Air Quality and Environmental Assessments. NASA TR R-473, 1977.

8. Wornom, Dewey E.; Woods, David C.; Thomas, Mitchel E.; and Tyson, Richard W.: Instrumentation of Sampling Aircraft for Measurement of Launch Vehicle Effluents. NASA TM X-3500, 1977.

9. Gregory, Gerald L.; Bendura, Richard J.; and Woods, David C.: Launch Vehicle Effluent Measurements During the May 12, 1977, Titan III Launch at Air Force Eastern Test Range. NASA TM-78753, 1979.

10. Wornom, Dewey E.; Bendura, Richard J.; and Gregory, Gerald L.: Launch Vehicle Effluent Measurements During the September 5, 1977, Titan III Launch at Air Force Eastern Test Range. NASA TM-80065, 1979.

11. Sebacher, Daniel I.; Wornom, Dewey E.; and Bendura, Richard J.: Hydrogen Chloride Partitioning in a Titan III Exhaust Cloud Diluted With Ambient Air. AIAA Paper 79-0299, 17th Aerospace Sciences Meeting, New Orleans, La., January 15-17, 1979.

12. Sebacher, Daniel I.: Airborne Nondispersive Infrared Monitor for Atmospheric Trace Gases. Rev. Sci. Instrum. 49, Nov. 1978, pp. 1520-1525.

13. Gregory, Gerald L.; and Moyer, Rudolph H.: Evaluation of a Hydrogen Chloride Detector for Environmental Monitoring. Rev. Sci. Instrum. 48, Nov. 1977, pp. 1464-1468.

Table I.- Aircraft Sampling Parameters
March 25, 1978 Launch

Pass Number	Sampling Altitude m	Aircraft Heading deg.	Time of Cloud Penetration after Launch sec
1	826	319	258
2	1146	251	426
3	1463	335	603
4	1568	238	788
5	1487	330	939
6	1501	207	1075
7	1495	315	1222
8	1481	217	1376
9	1486	49	1525
10	1490	240	1695
11	1514	330	1865
12	1480	238	2126
13	1515	330	2288
14	1496	235	2553
15	1495	326	2735
16	1484	247	3011
17	1494	340	3238
18	1500	240	3461
19	1500	332	3687
20	1470	242	4008
21	1503	330	4257
22	1480	243	4574
23	1487	330	4746
24	1502	243	4975
25	-	-	-
26	1500	239	5536
27	1496	332	5745
28	1481	243	6072
29	1487	339	6262
30	1478	59	6498

Table II.- Aircraft Sampling Parameters
December 13, 1978 Launch

Pass Number	Sampling Altitude m	Aircraft Heading deg.	Time of Cloud Penetration after Launch sec
1	818	110	197
2	917	100	310
3	919	85	453
4	992	210	595
5	1200	125	909
6	1260	300	1055
7	1260	150	1176
8	1270	40	1357
9	1250	103	1692
10	1220	44	1852
11	1220	110	1978

Table III.- Aircraft Sampling Parameters
November 21, 1979 Launch

Pass Number	Sampling Altitude m	Aircraft Heading deg.	Time of Cloud Penetration after Launch sec
1	1220	205	265
2	1315	295	335
3	1566	207	505
4*	1403	278	655
5	1577	208	945
6	1525	295	1085
7	1479	280	1225
8*	1400	350	1325

*under the cloud

Table IV.- Peak HCℓ Concentration Measured with Geomet and GFC March 25, 1978 Launch

Pass Number	Peak Concentrations (ppmv)	
	Geomet	GFC
1	4.8	-
2	11.5	1.5
3	15.6	1.5
4	18.0	2.0
5	12.5	2.5
6	10.7	2.5
7	10.0	2.3
8	10.0	2.1
9	7.7	1.2
10	5.3	1.3
11	7.6	1.6
12	5.6	1.5
13	6.0	1.5
14	3.5	1.2
15	4.5	1.0
16	4.3	1.3
17	2.2	-
18	3.1	0.9
19	5.0	0.9
20	3.4	1.0
21	3.2	0.8
22	3.6	0.6
23	3.3	0.8
24	2.9	0.8
25	-	-
26	2.7	0.7
27	3.7	0.9
28	2.0	-
29	2.0	-
30	2.6	0.6

Table V.- Peak HCℓ Concentration Measured with Geomet and GFC December 13, 1978 Launch

Pass Number	Peak Concentrations (ppmv)	
	Geomet	GFC
1	16.0	1.6
2	9.7	1.2
3	9.2	0.8
4	1.7	0.5
5	1.9	0.4
6	1.6	0.5
7	1.0	0.5
8	0.7	-
9	0.6	0.3
10	0.7	0.3
11	1.6	0.3

Table VI.- Peak HCℓ Concentrations Measured with Geomet and GFC 21 November 1979 Launch

Pass Number	Peak Concentration (ppmv)	
	Geomet	GFC
1	3.8	0.4
2	1.9	0.2
3	3.7	0.3
4	0.8	0.1
5	0.8	0.1
6	0.5	0.1
7	0.3	0.1
8	0.3	0.1

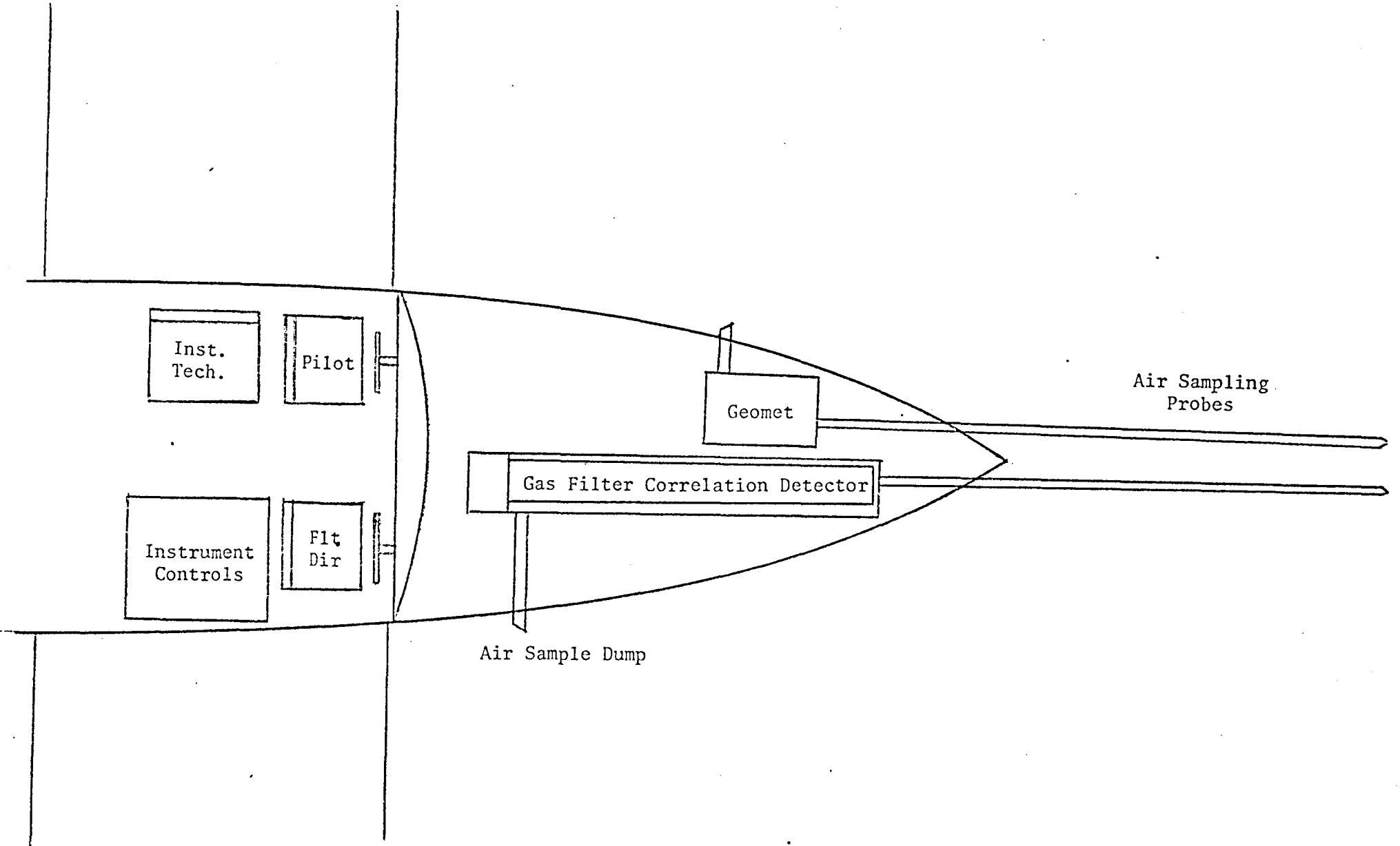


Figure 1.- Aircraft instrumentation. (Cessna 402)

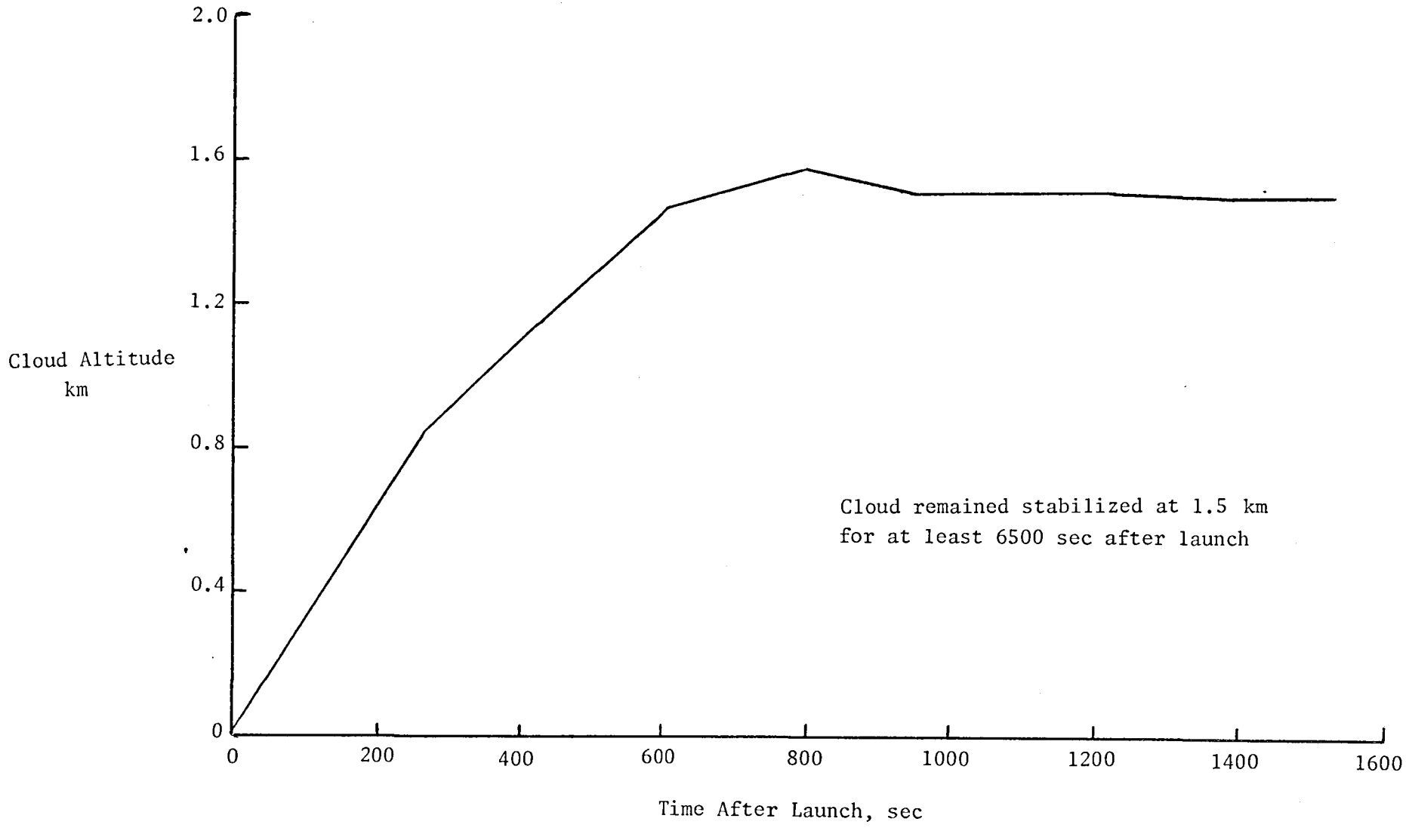


Figure 2. - Cloud altitude stabilization measured by aircraft penetration. March 25, 1978

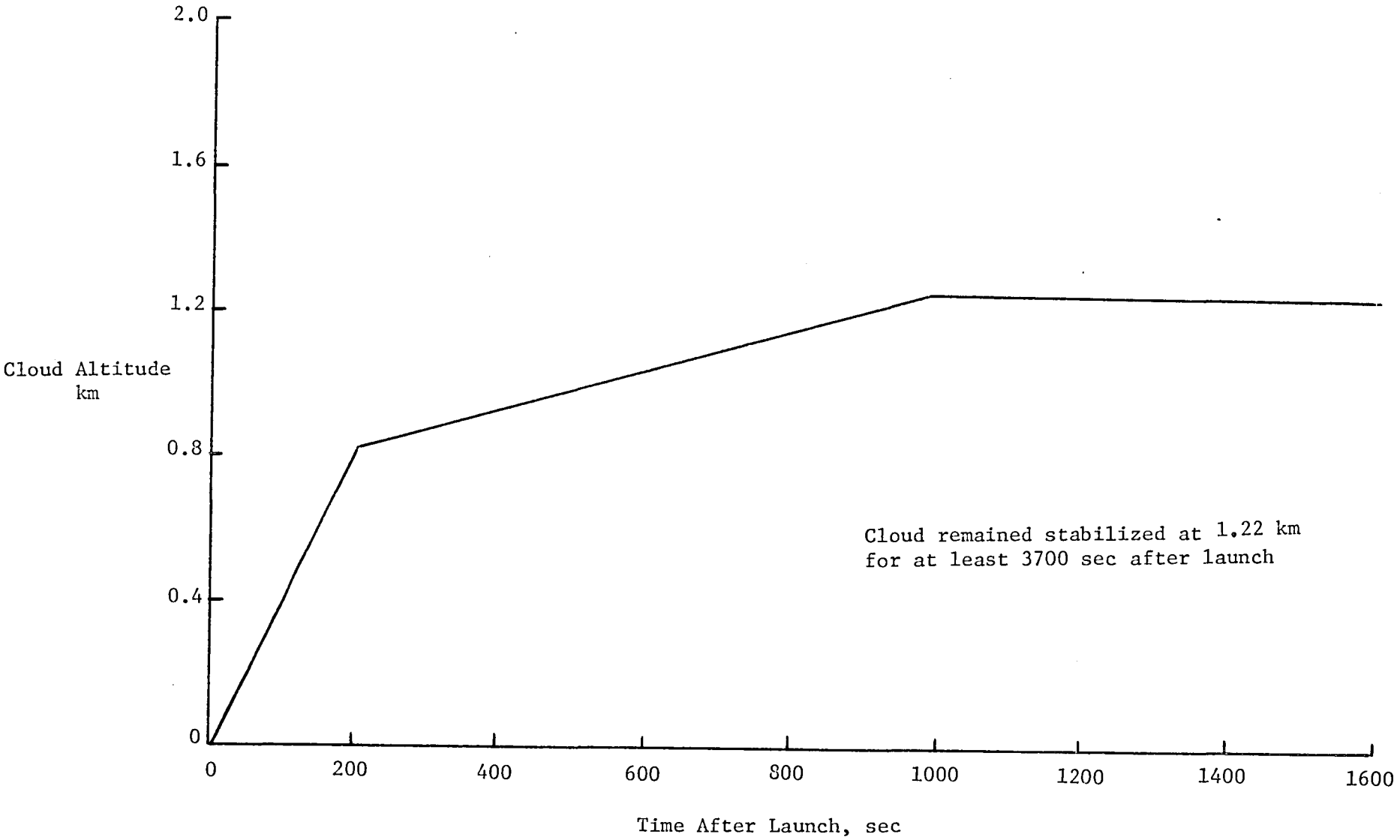


Figure 3.- Cloud altitude stabilization measured by aircraft penetration.
December 13, 1978

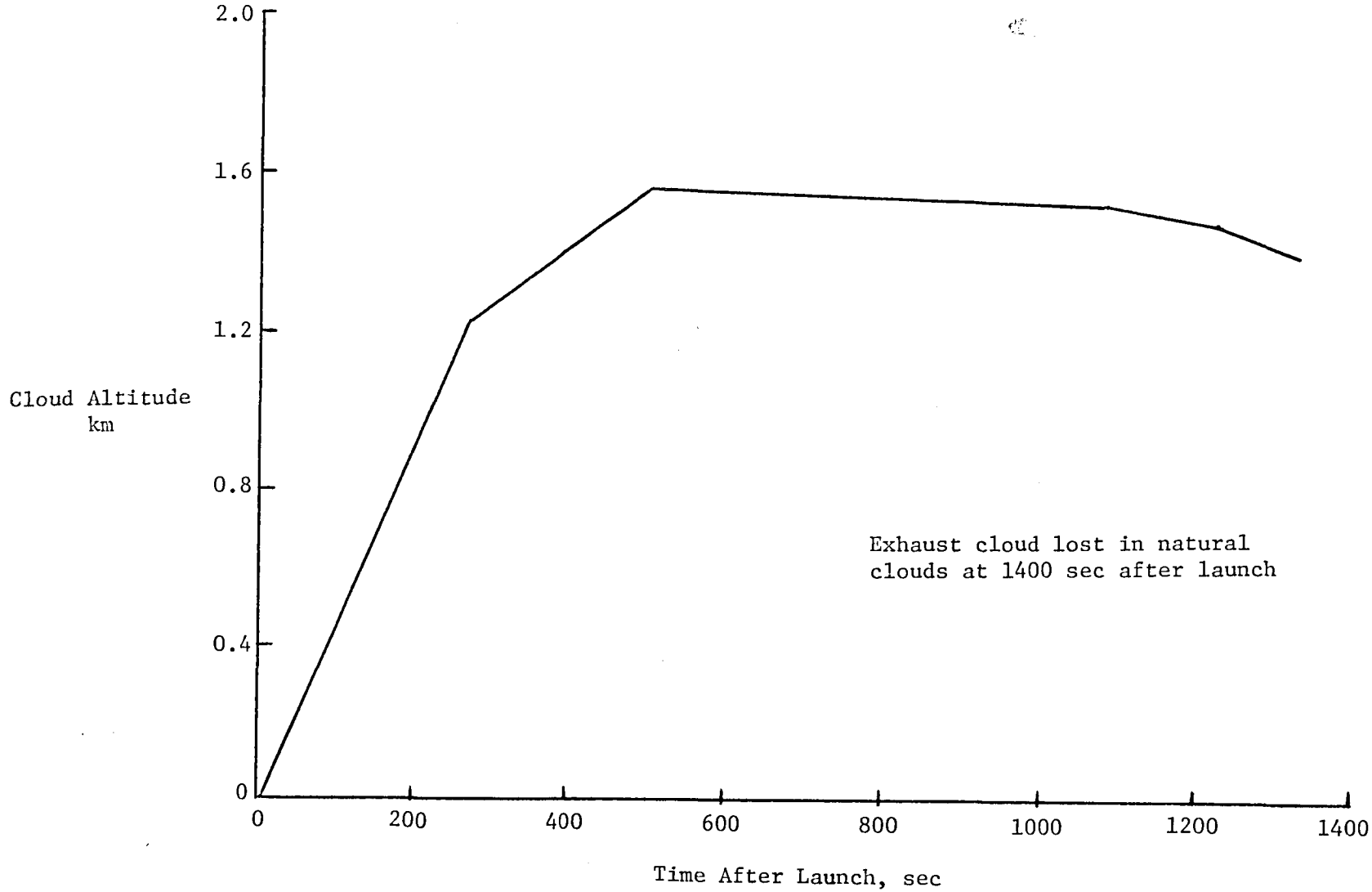


Figure 4.- Cloud altitude stabilization measured by aircraft penetration.
November 21, 1979

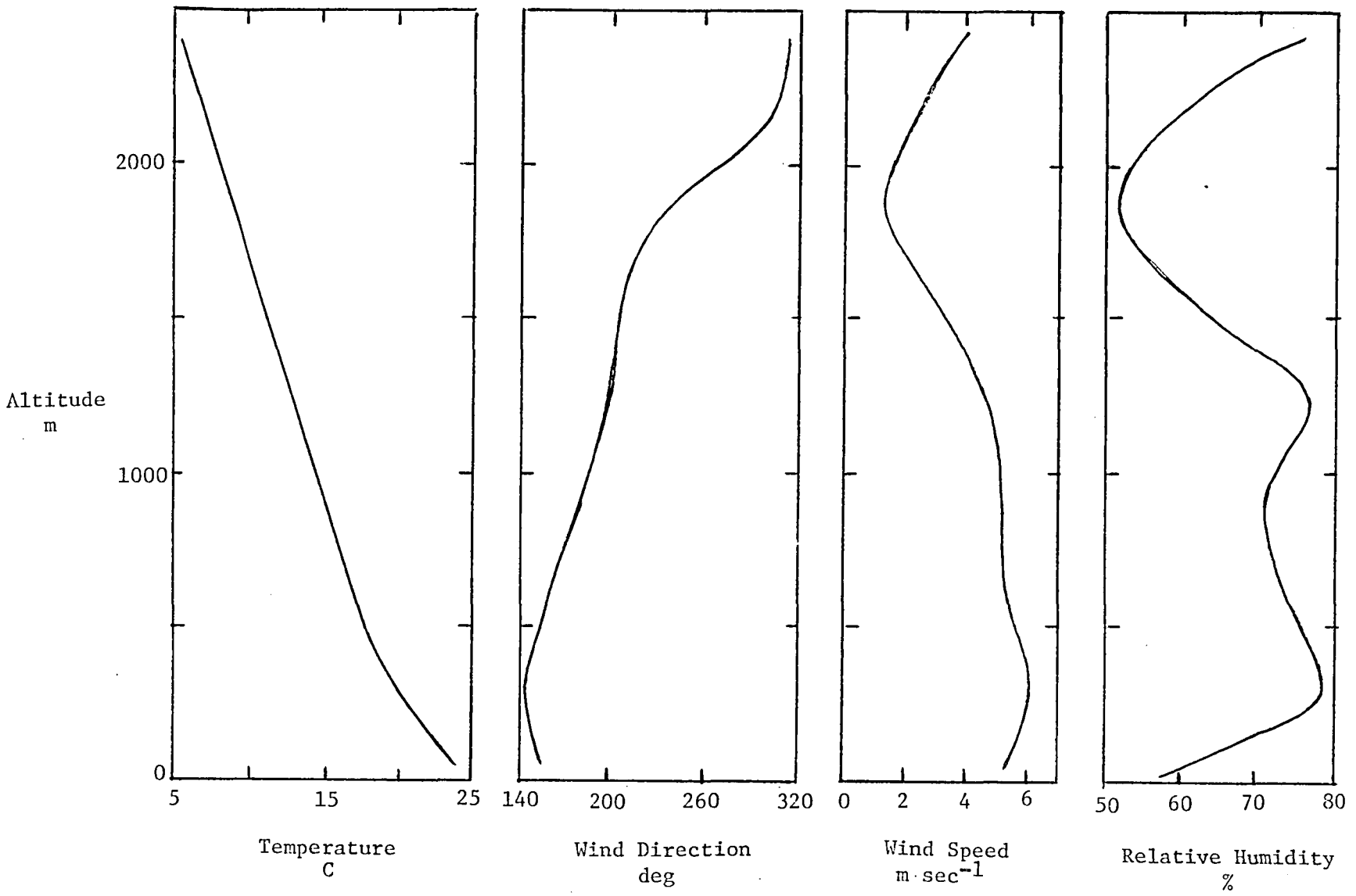


Figure 5.- Vertical profiles of temperature, wind direction, wind speed, and relative humidity at Kennedy Space Center from rawinsonde measurements for March 25, 1978, T - 40 minutes.

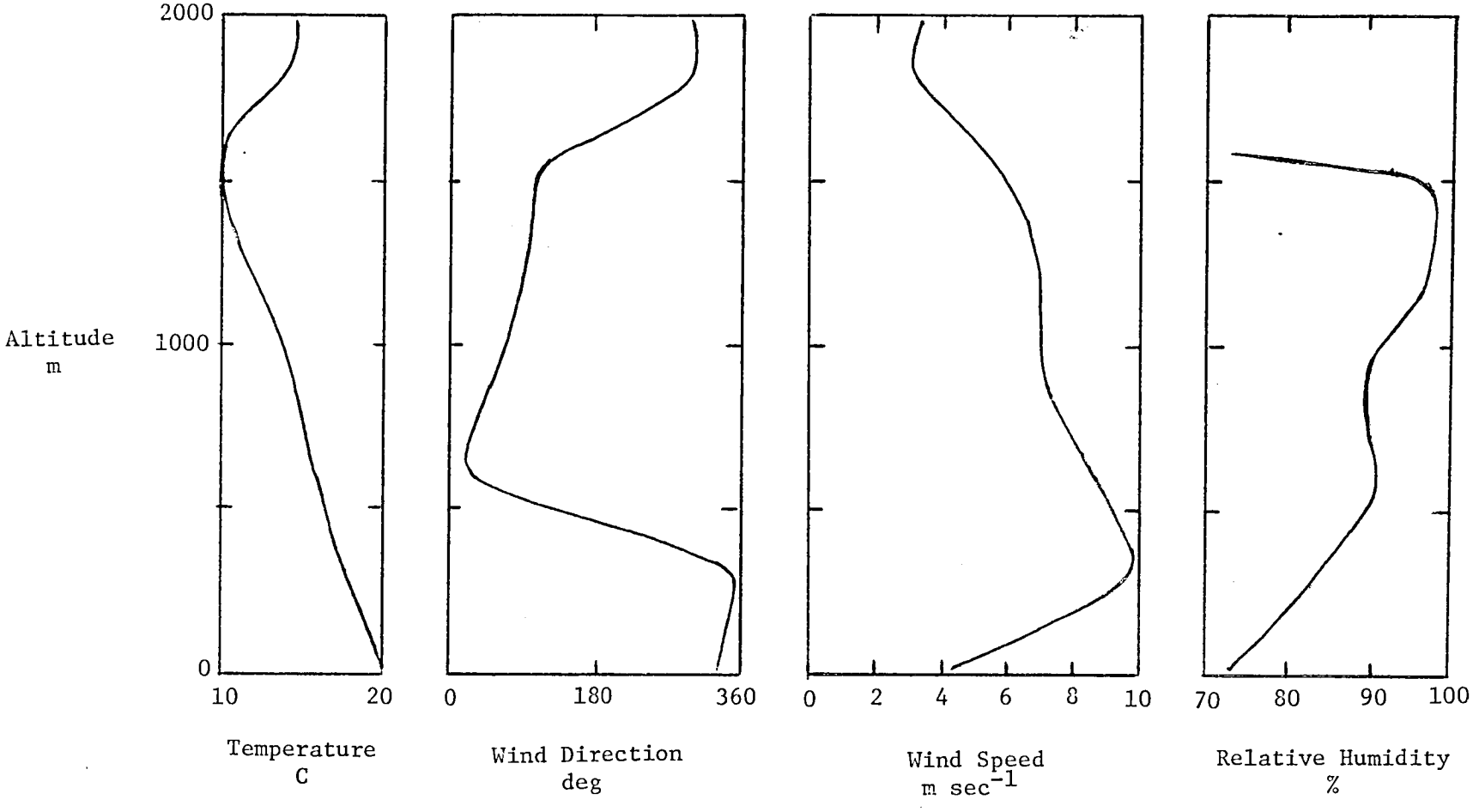


Figure 6.- Vertical profiles of temperature, wind direction, wind speed, and relative humidity at Kennedy Space Center from rawinsonde measurements for December 13, 1978, T + 40 minutes.

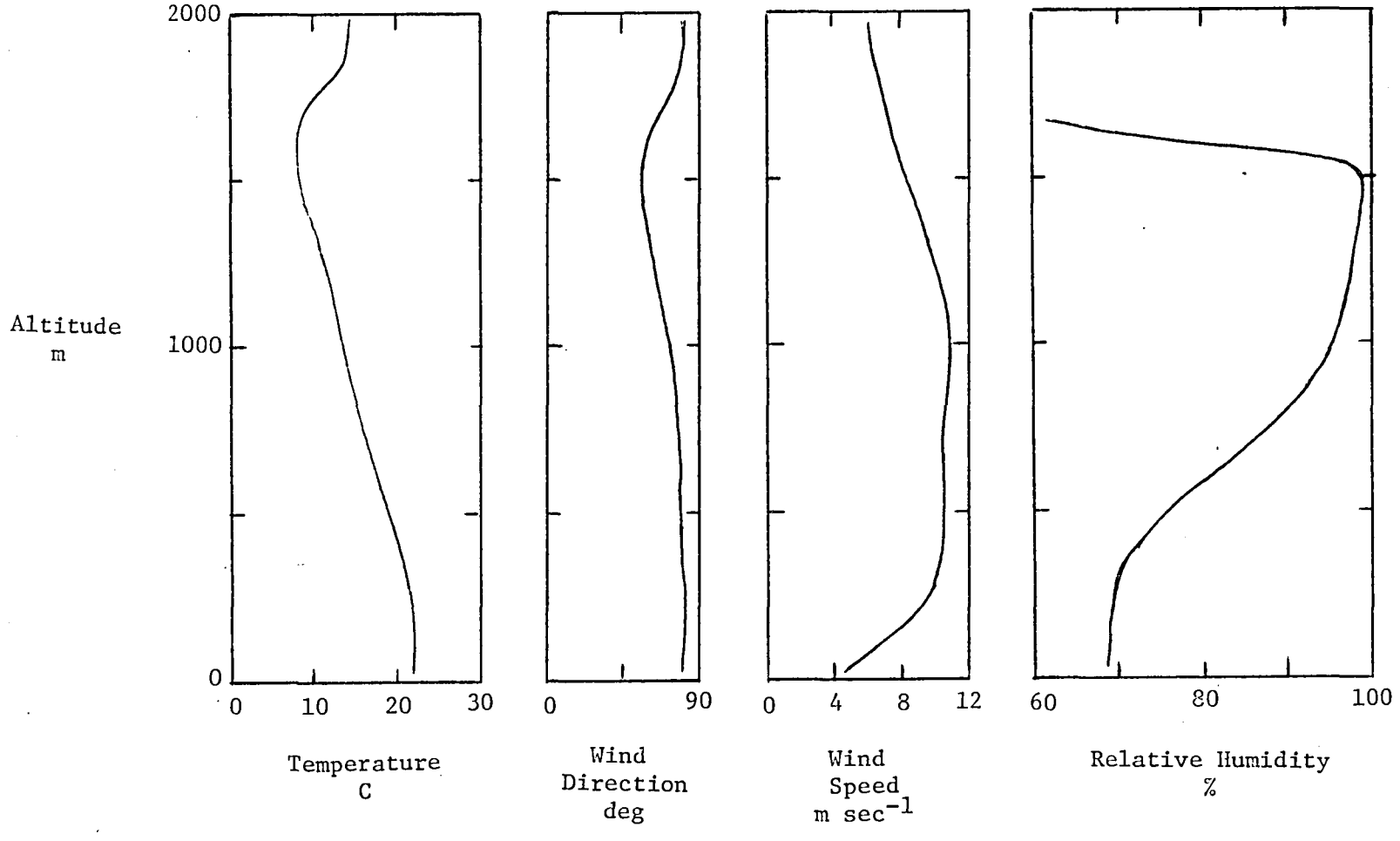


Figure 7.- Vertical profiles of temperature, wind direction, wind speed, and relative humidity at Kennedy Space Center from rawinsonde measurements for November 21, 1979, T - 40 minutes.

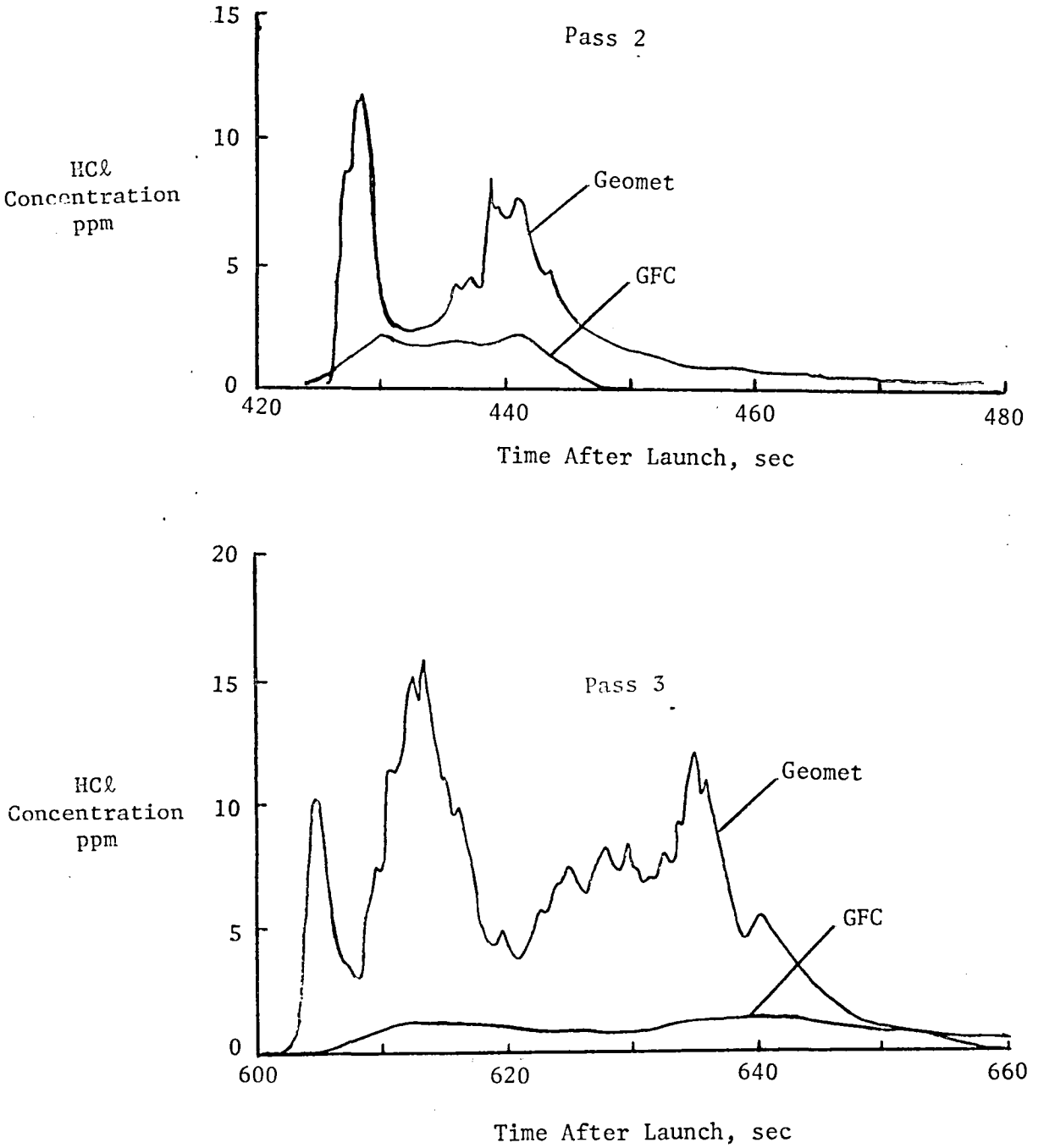


Figure 8.- Measured hydrogen chloride concentrations obtained incloud with airborne sensors versus time after launch. March 25, 1978

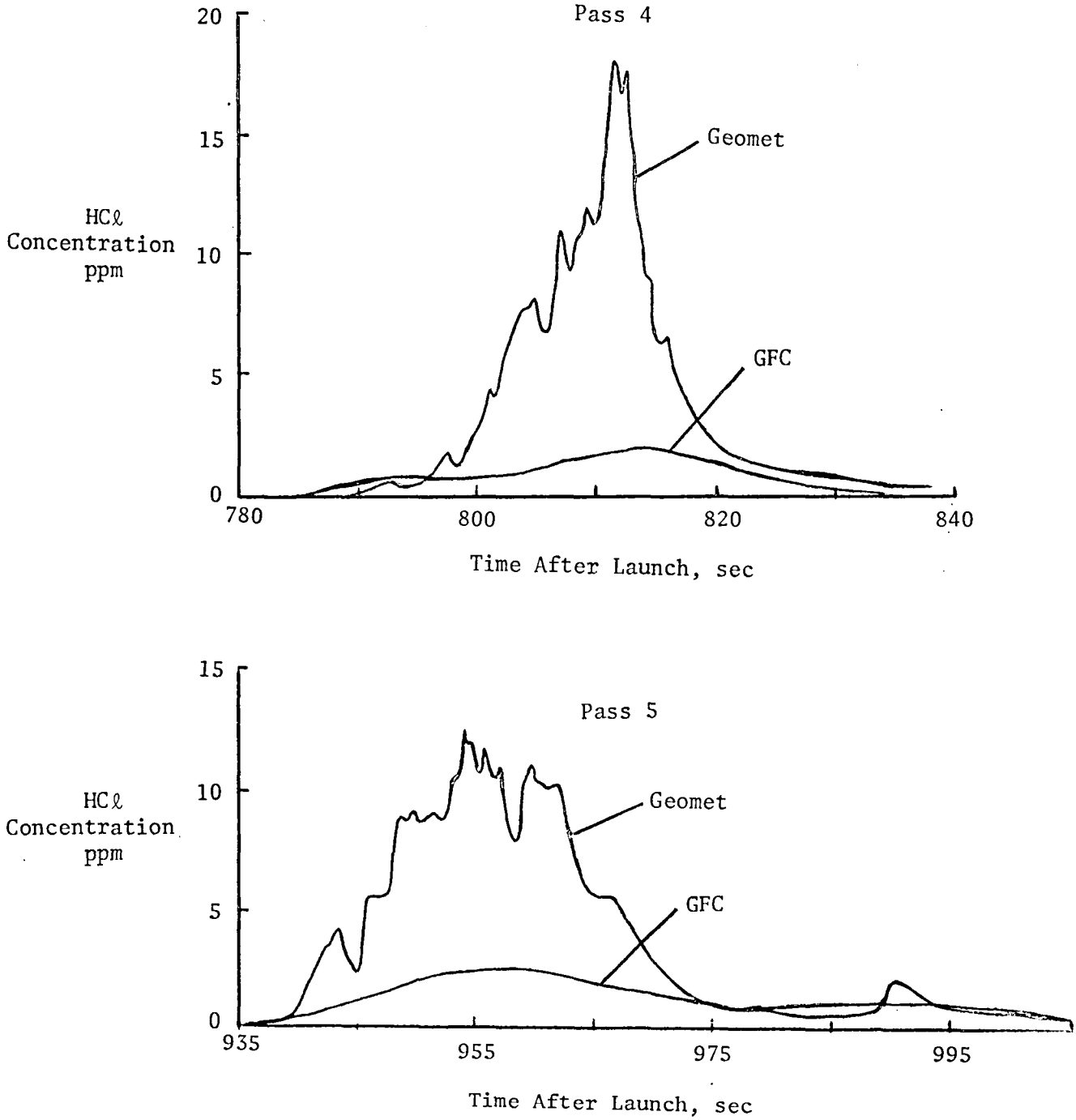
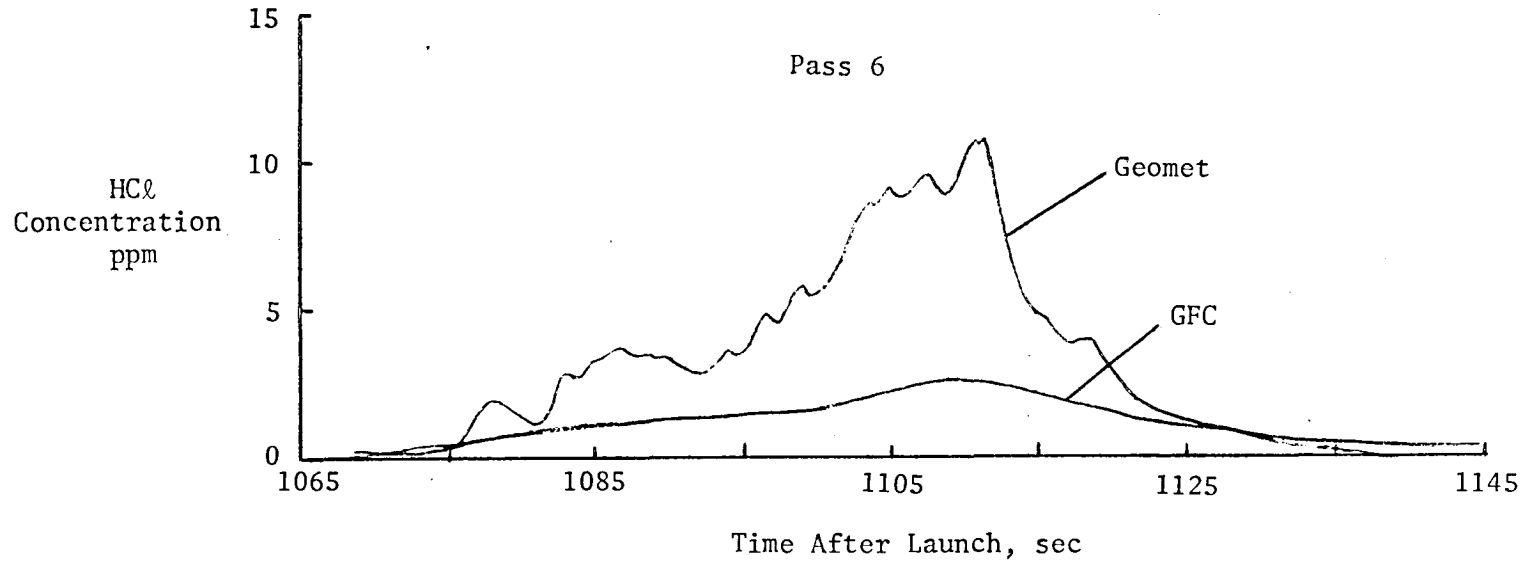


Figure 8. - Continued.



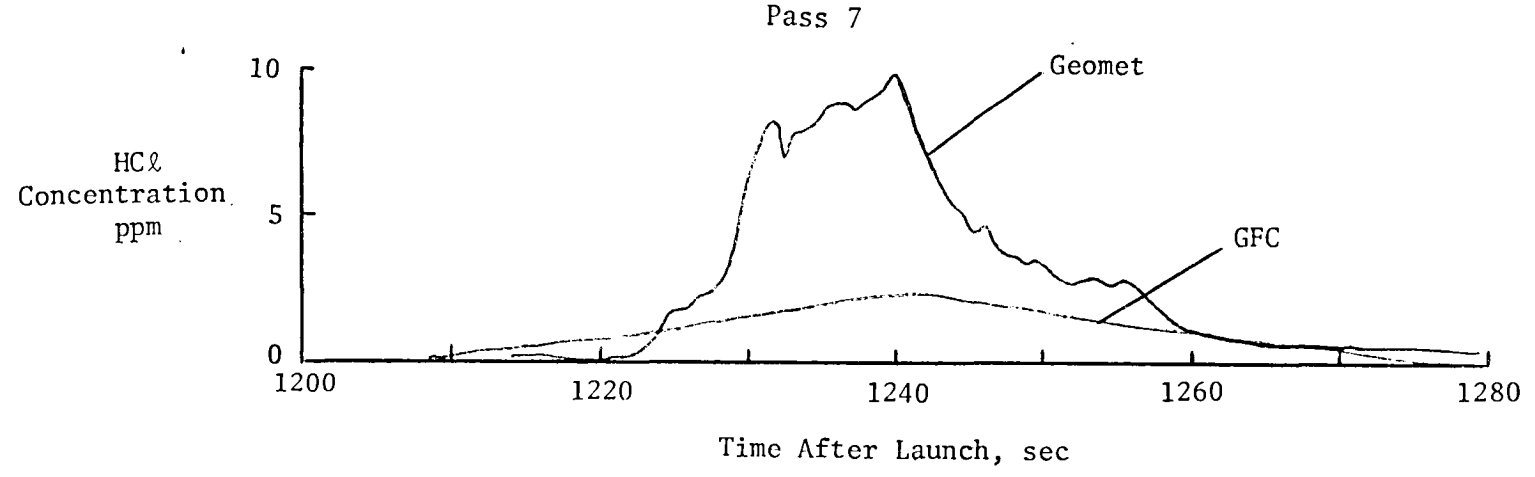
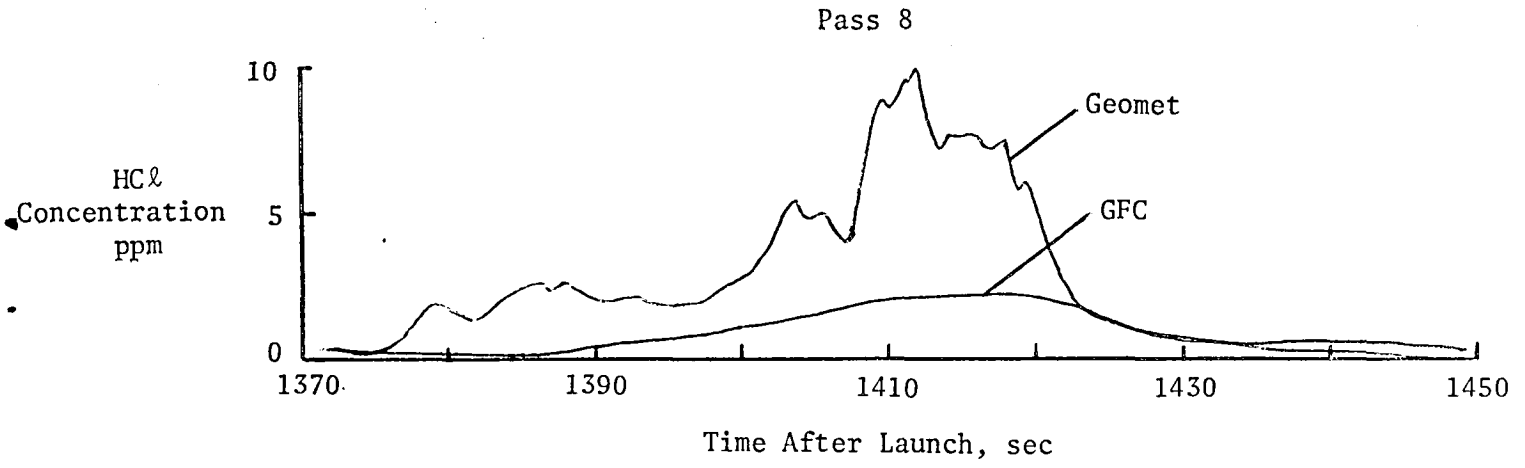
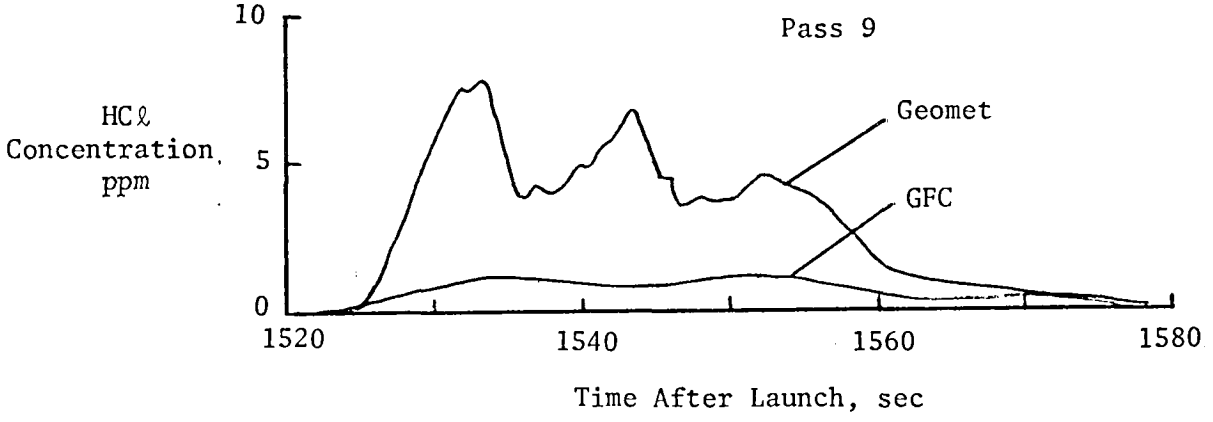


Figure 8. - Continued.





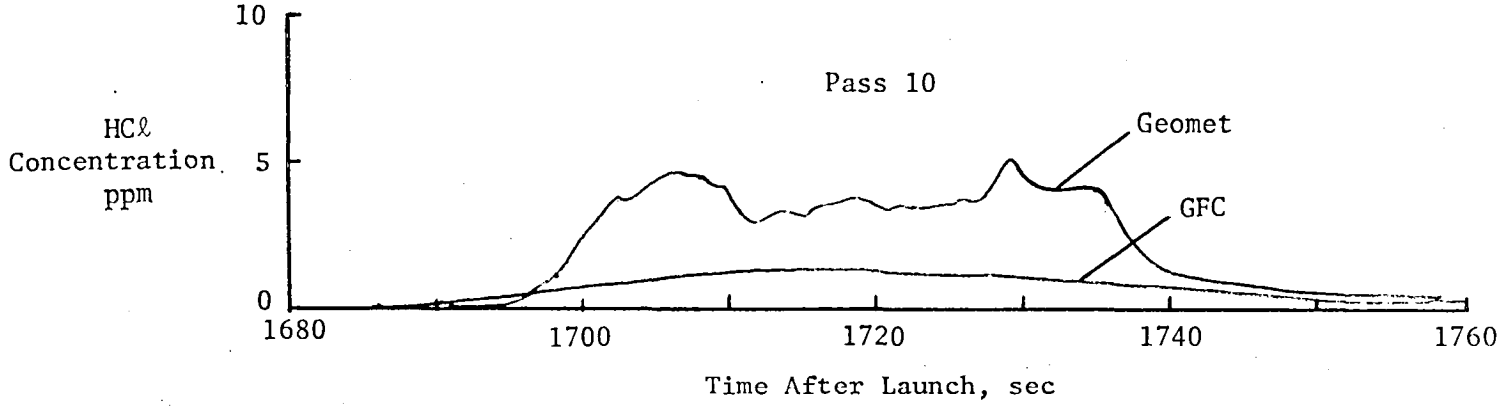


Figure 8. - Continued.

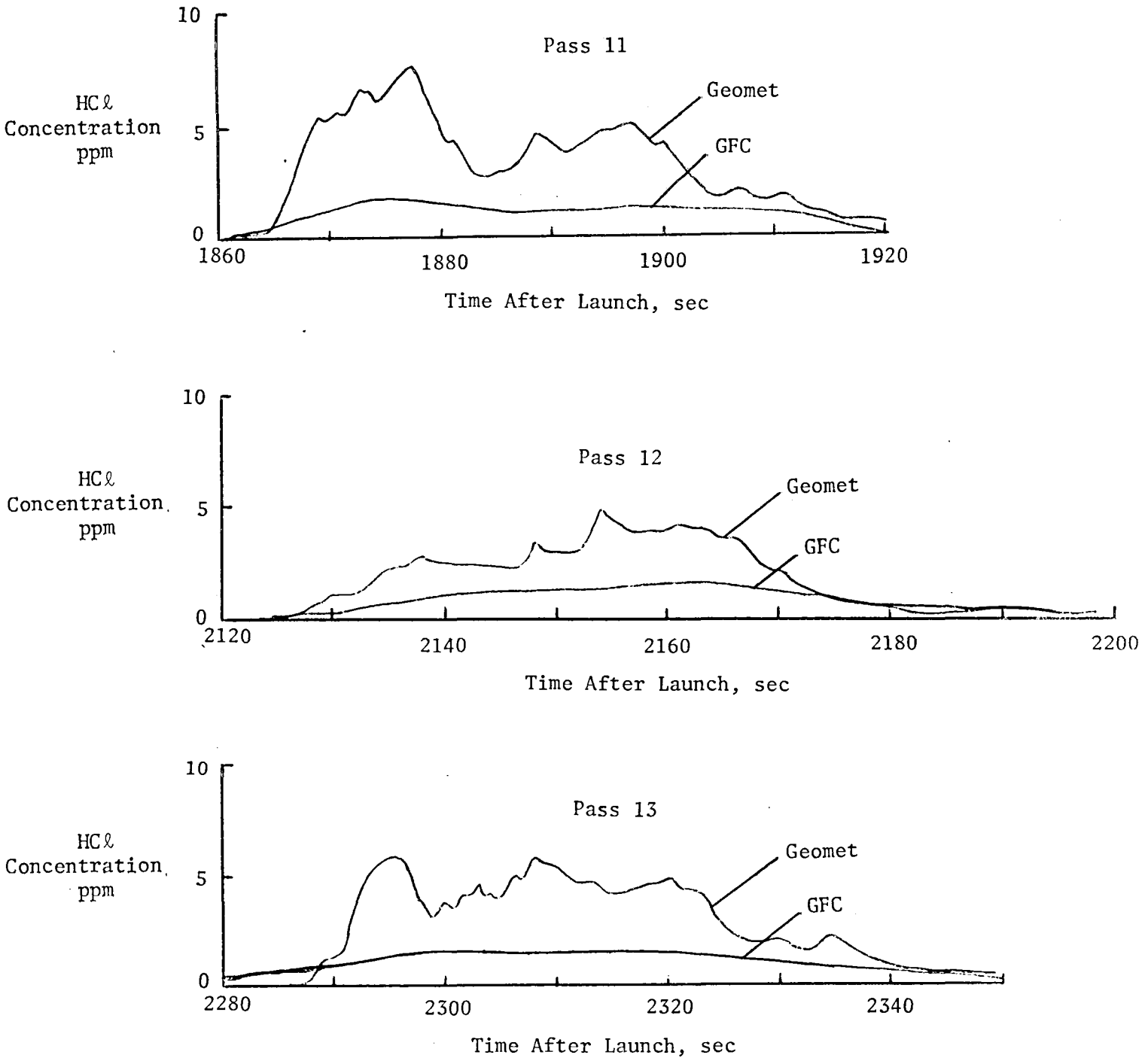


Figure 8. - Continued.

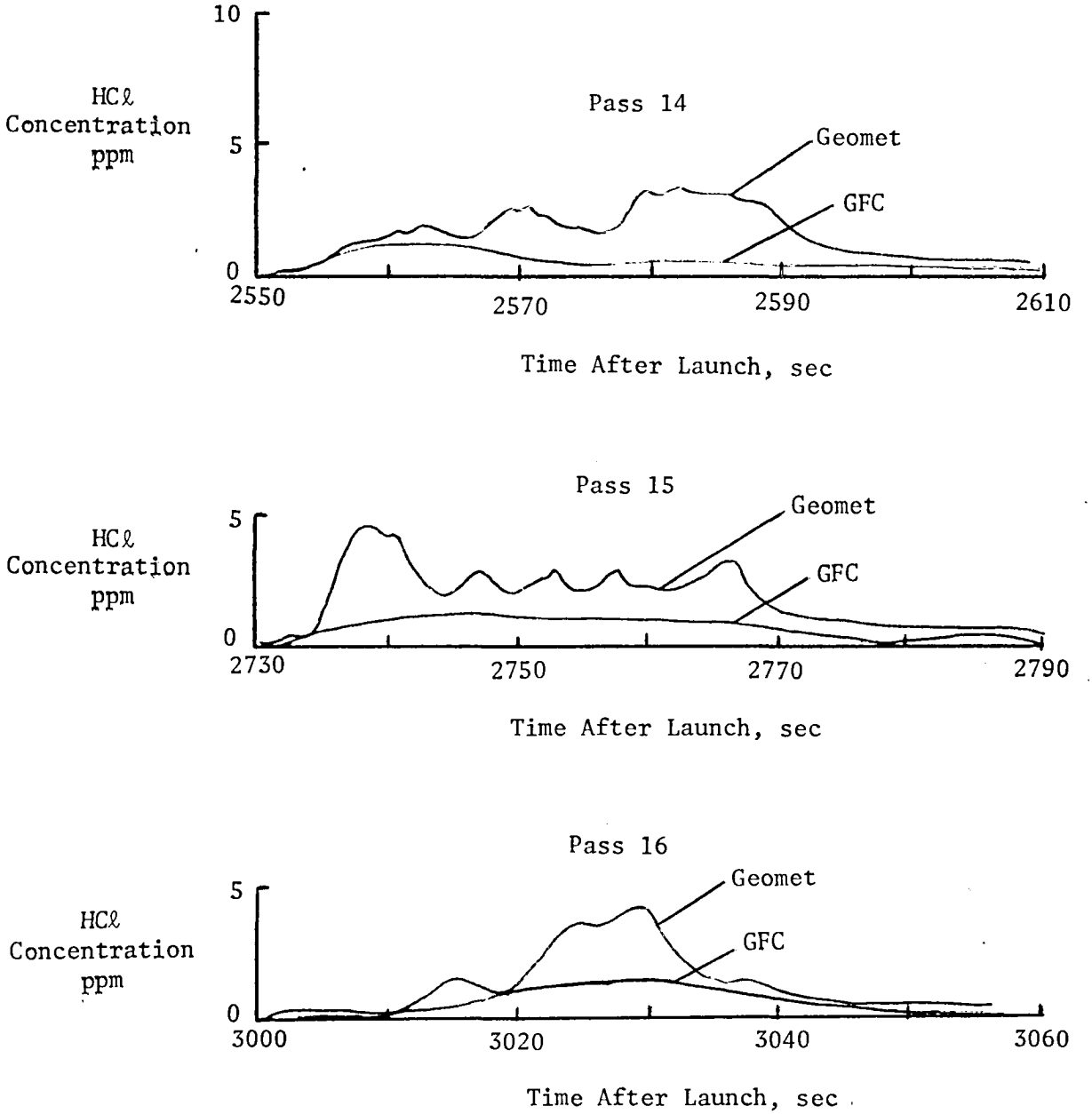


Figure 8. - Continued.

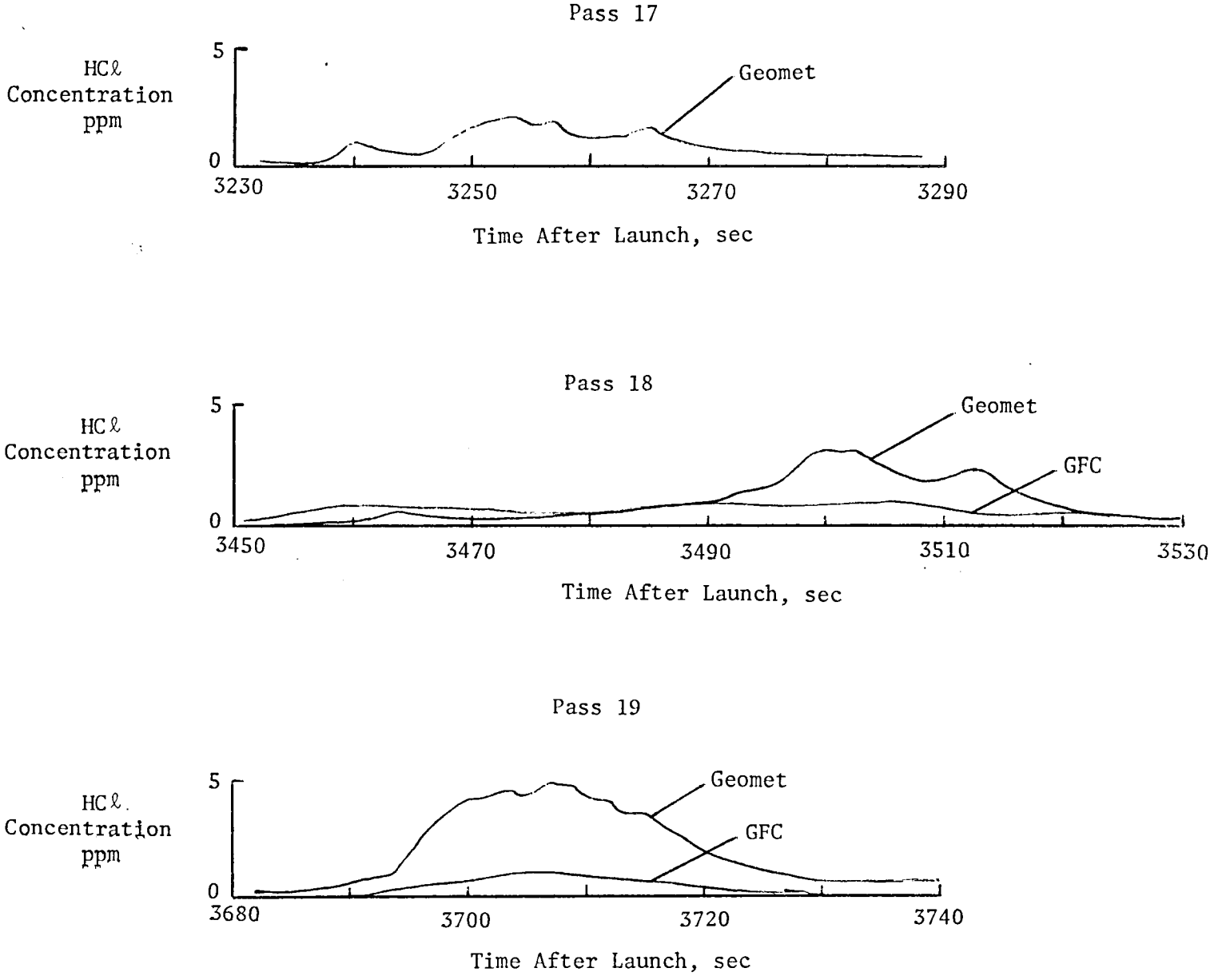


Figure 8. - Continued.

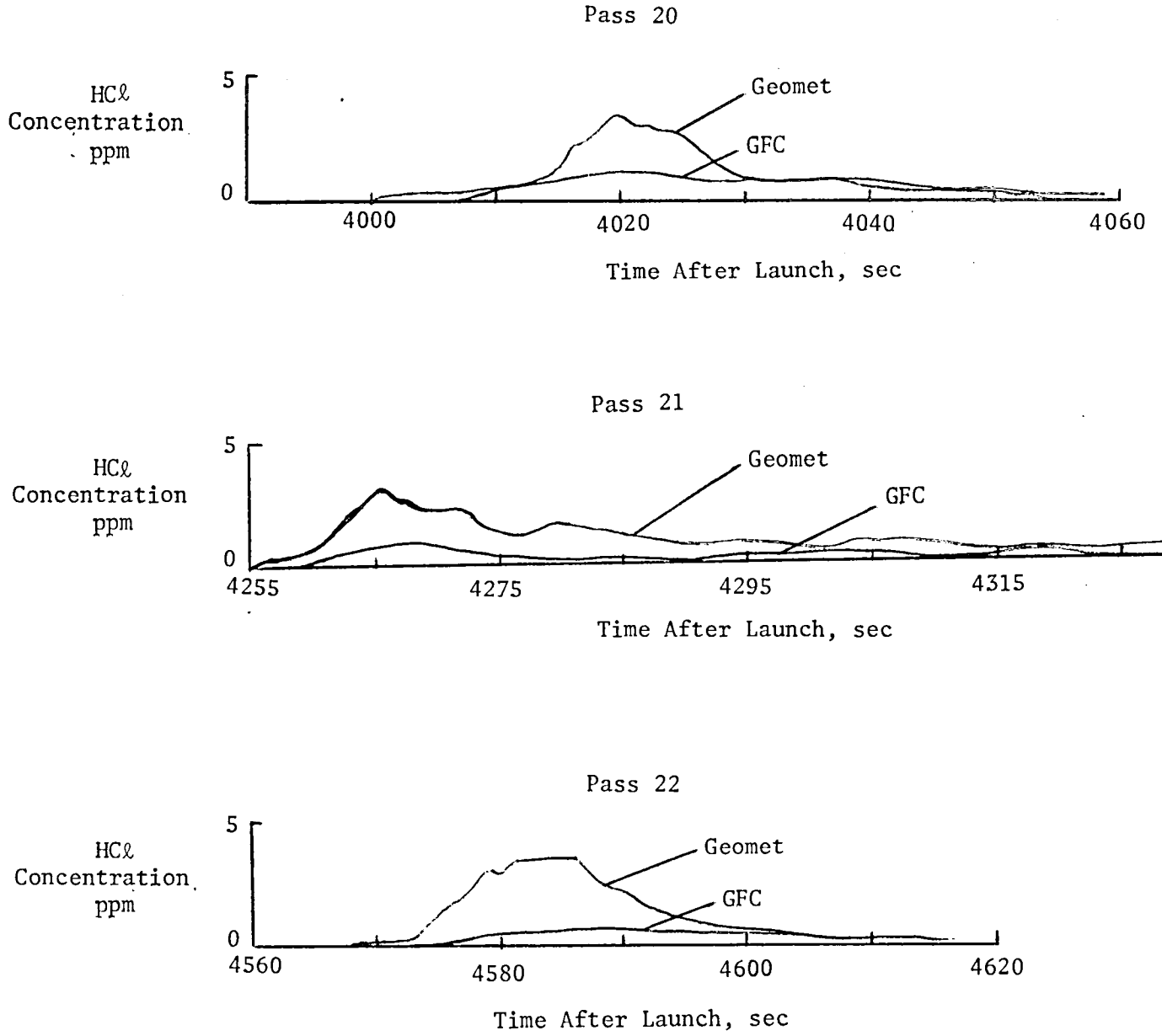


Figure 8. - Continued.

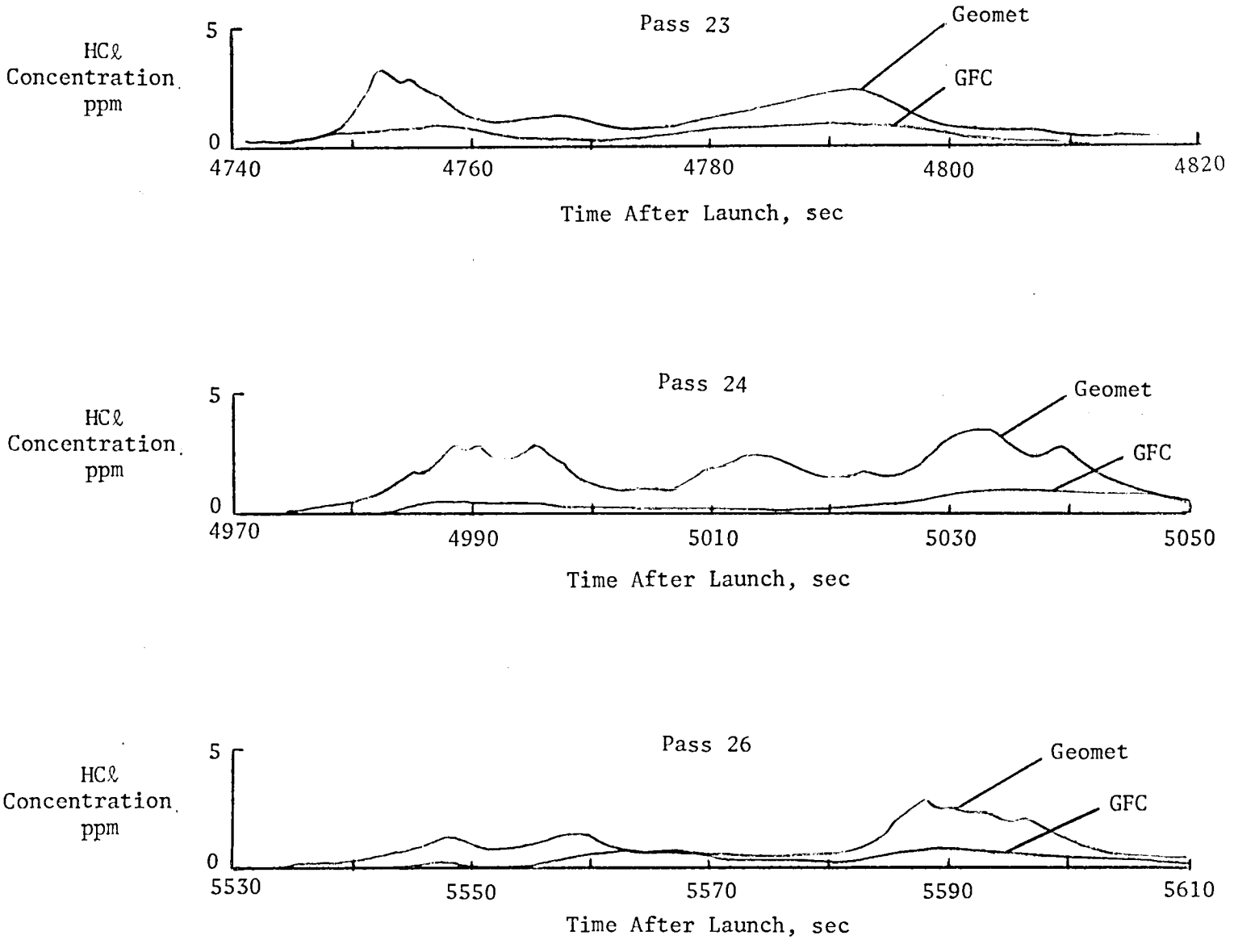


Figure 8. - Continued.

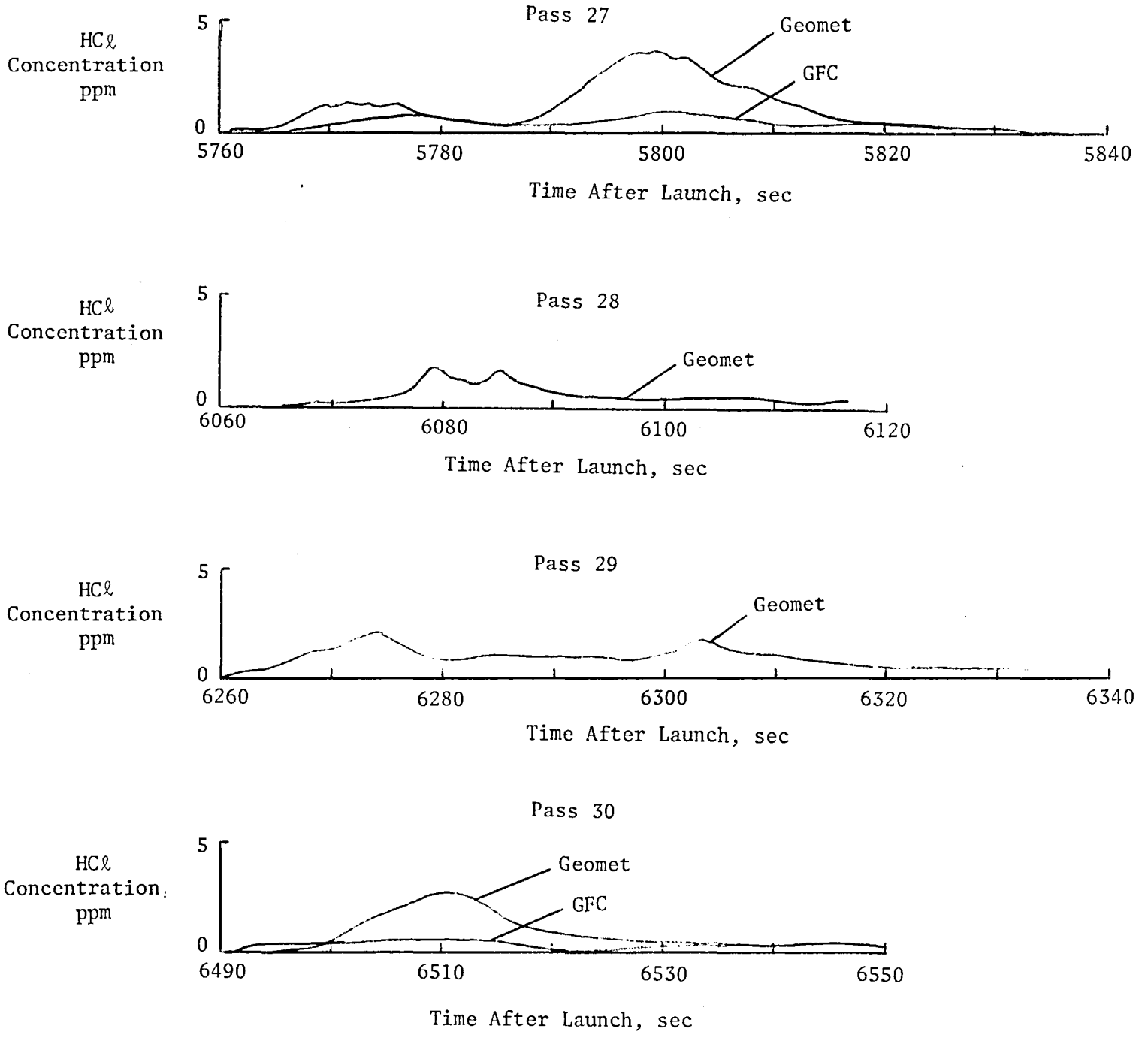


Figure 8. - Continued.

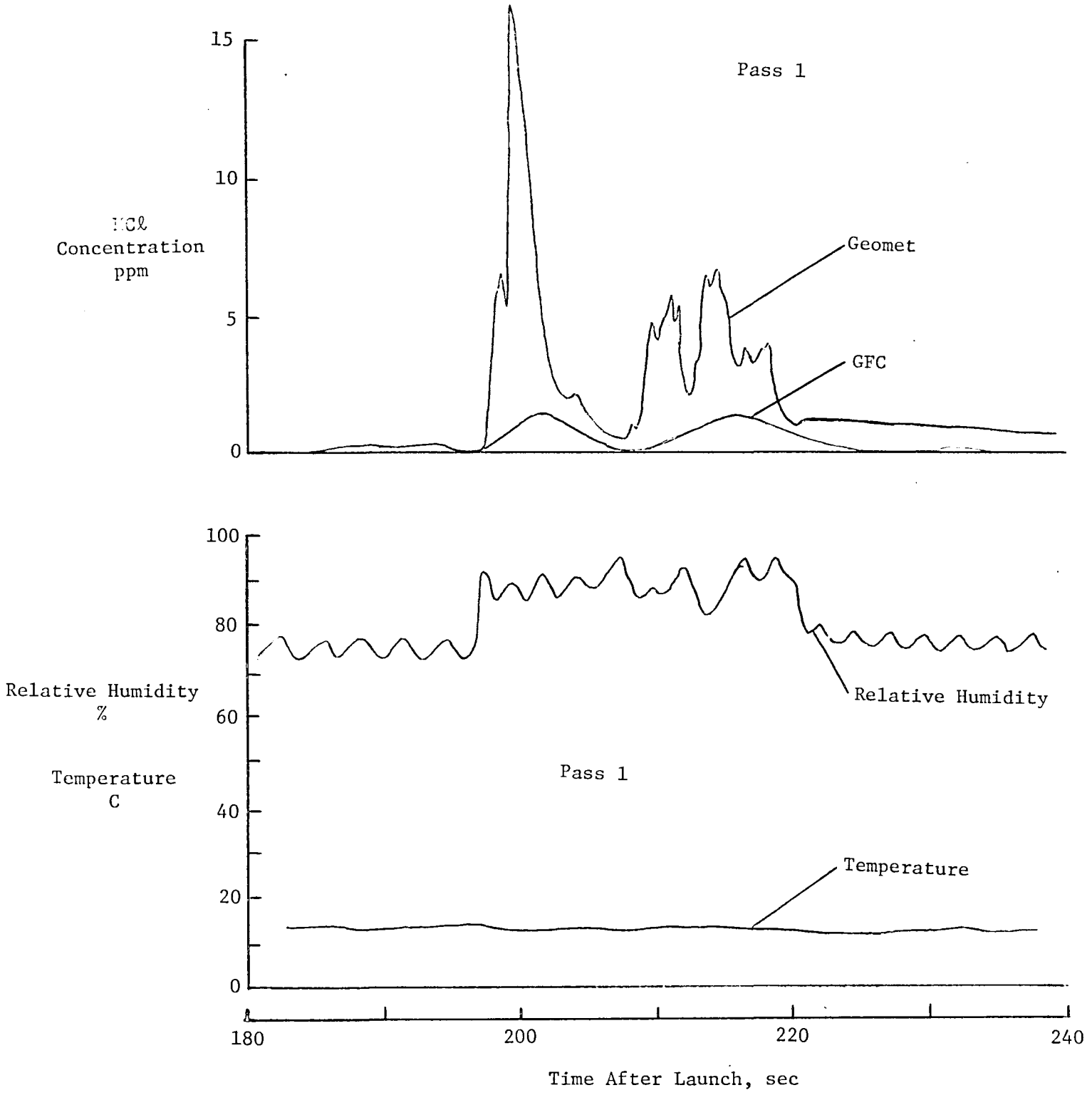


Figure 9.- Measured hydrogen chloride concentrations, relative humidity and temperature obtained in-cloud with airborne sensors versus time after launch. December 13, 1978

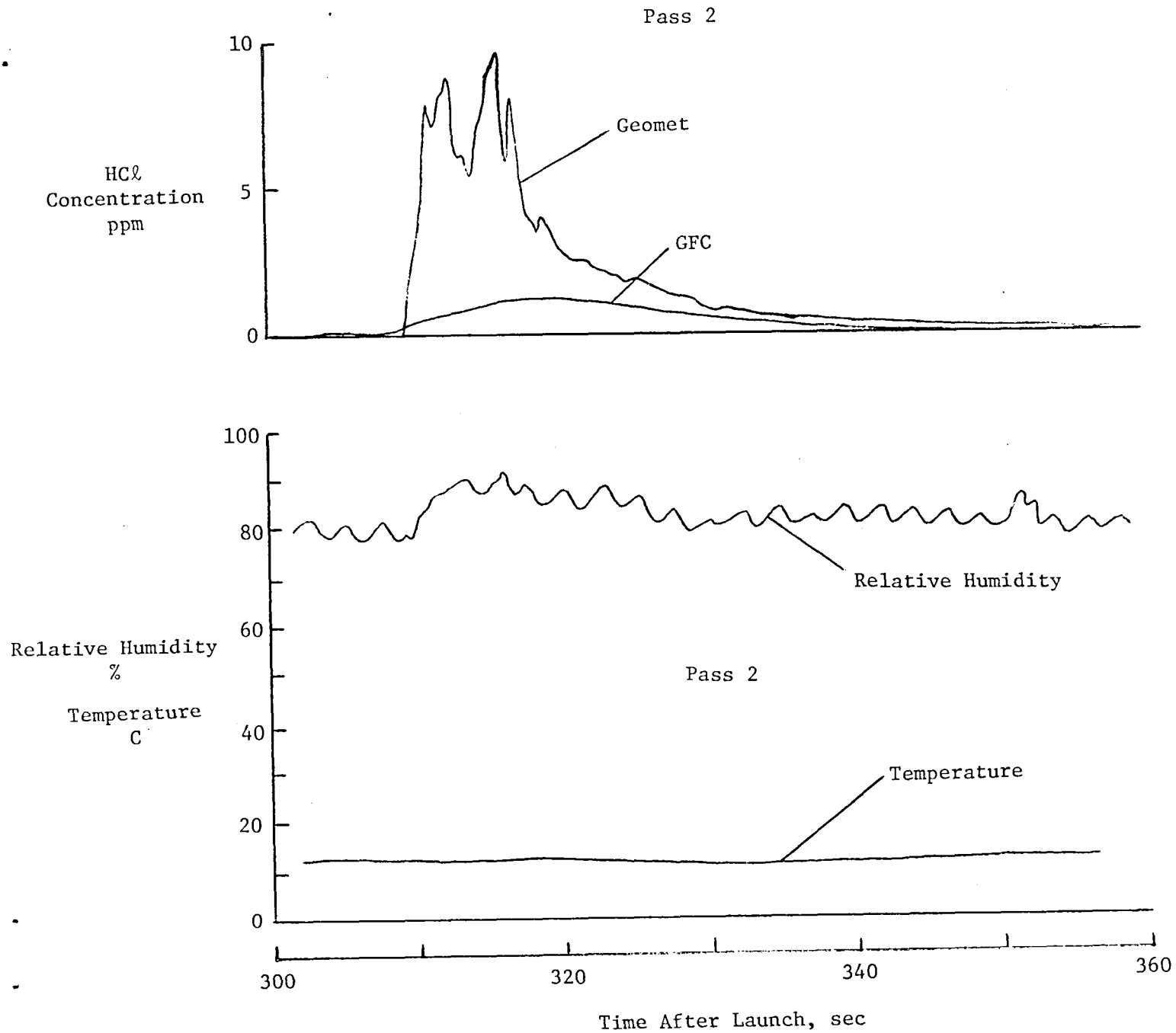


Figure 9.- Continued.

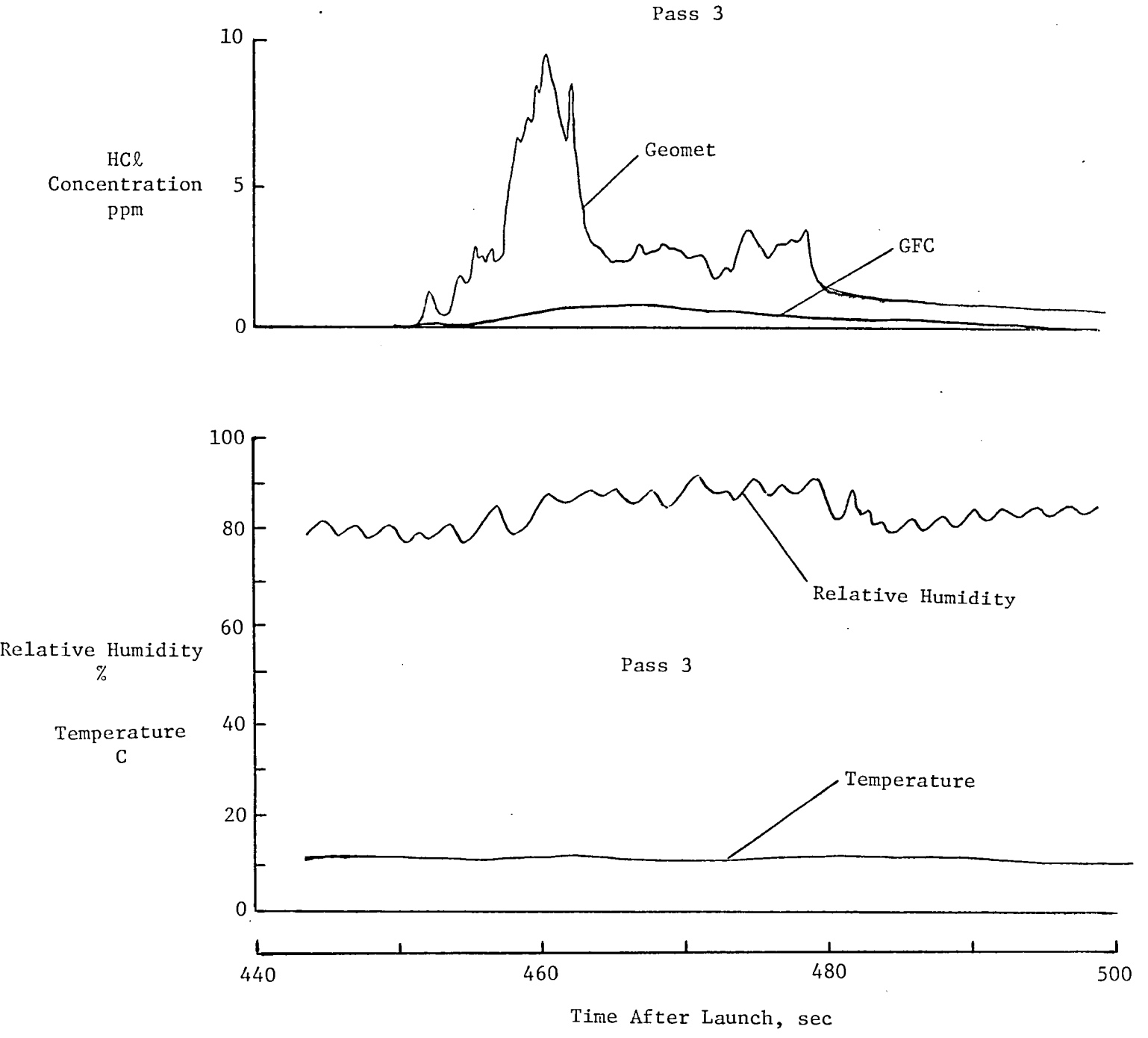


Figure 9.- Continued.

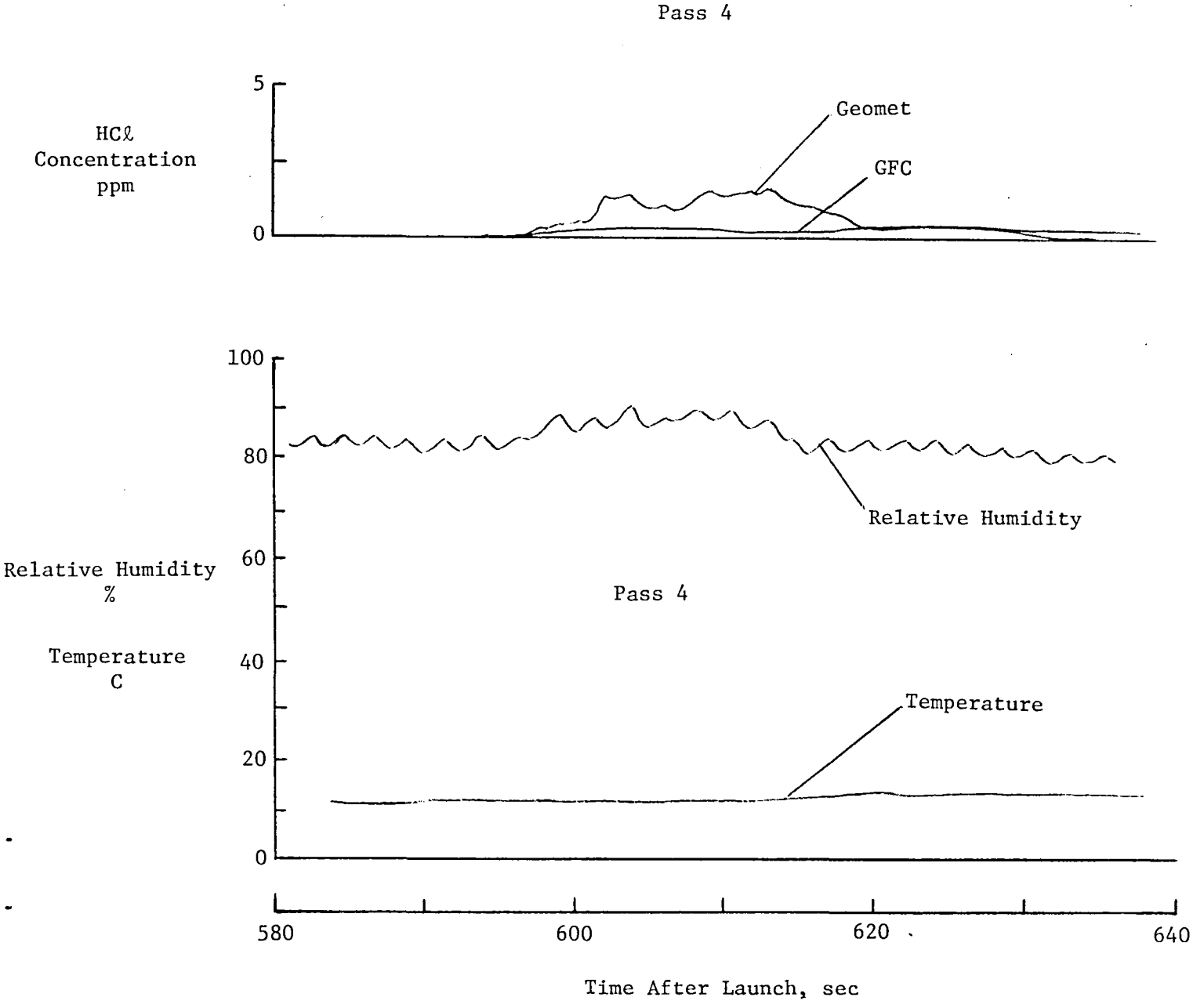


Figure 9.- Continued.

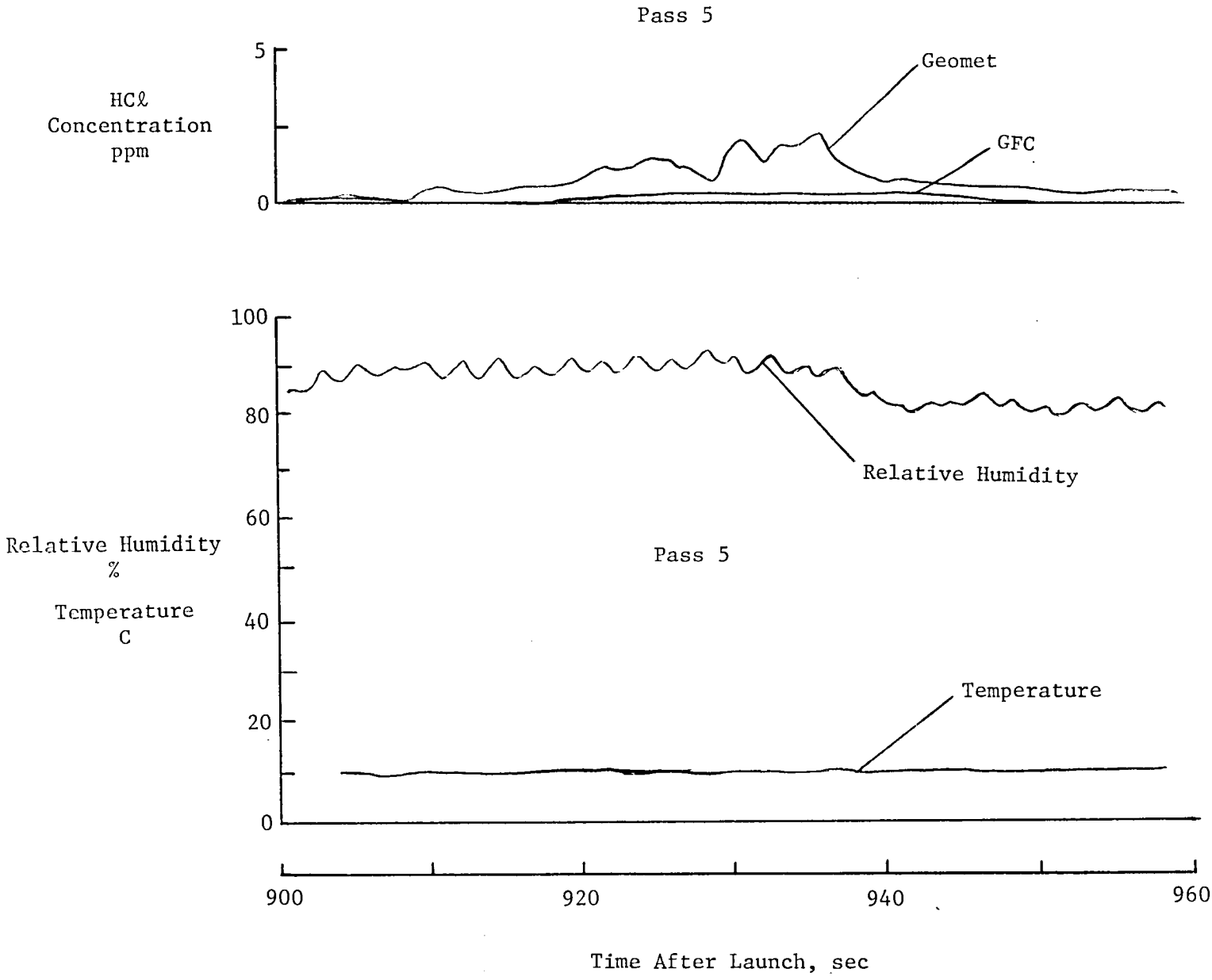


Figure 9.- Continued.

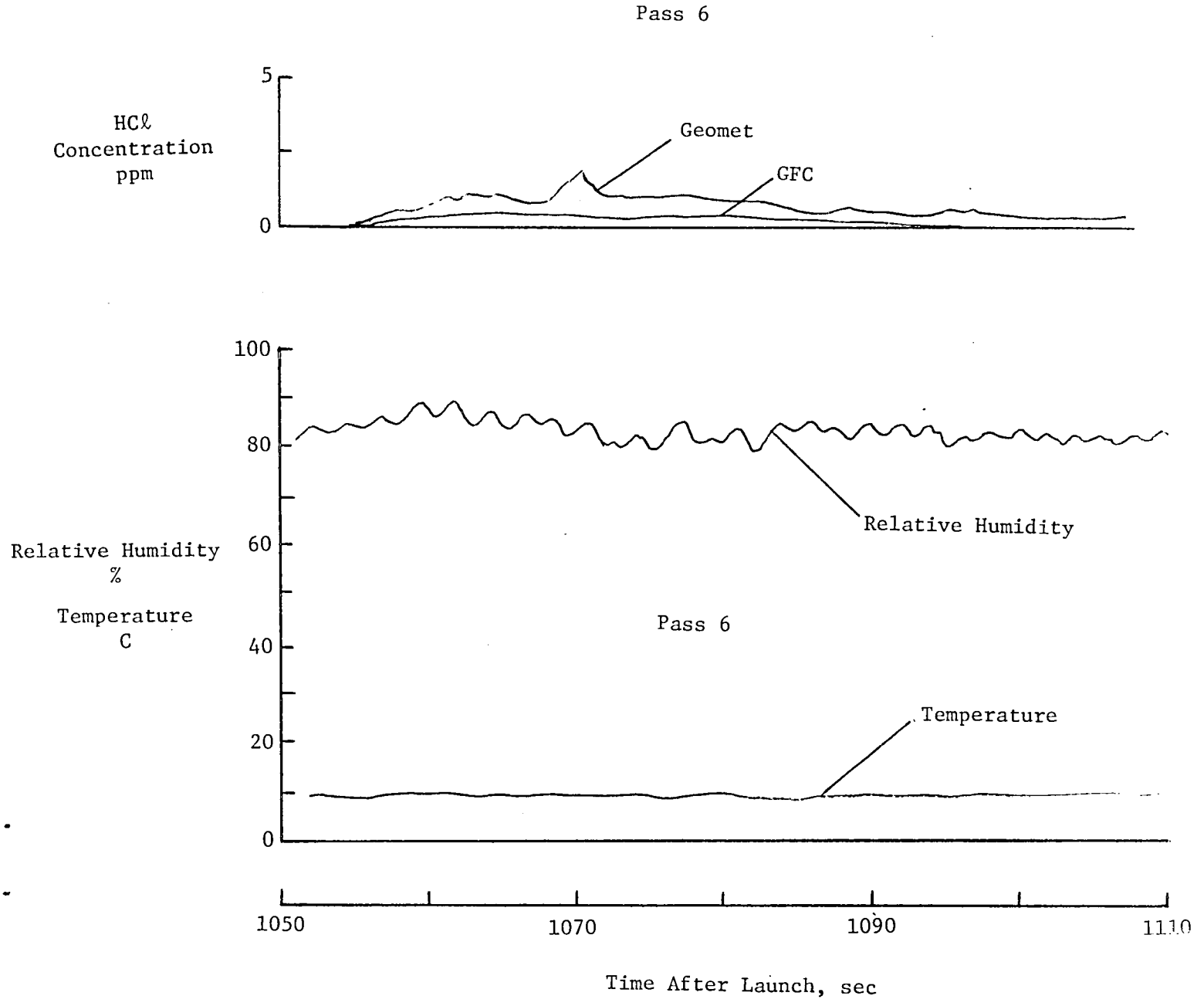


Figure 9.- Continued.

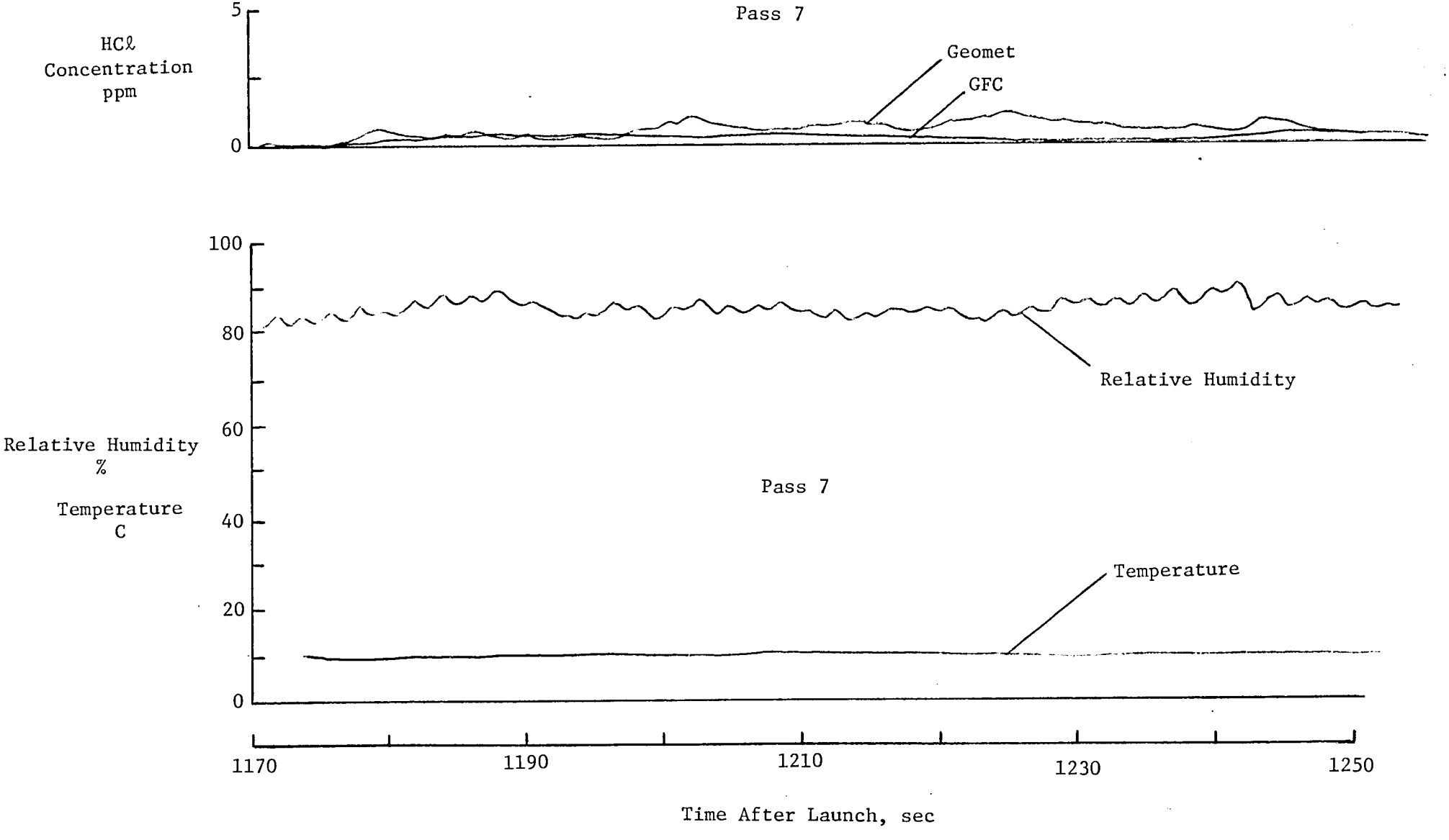


Figure 9.- Continued.

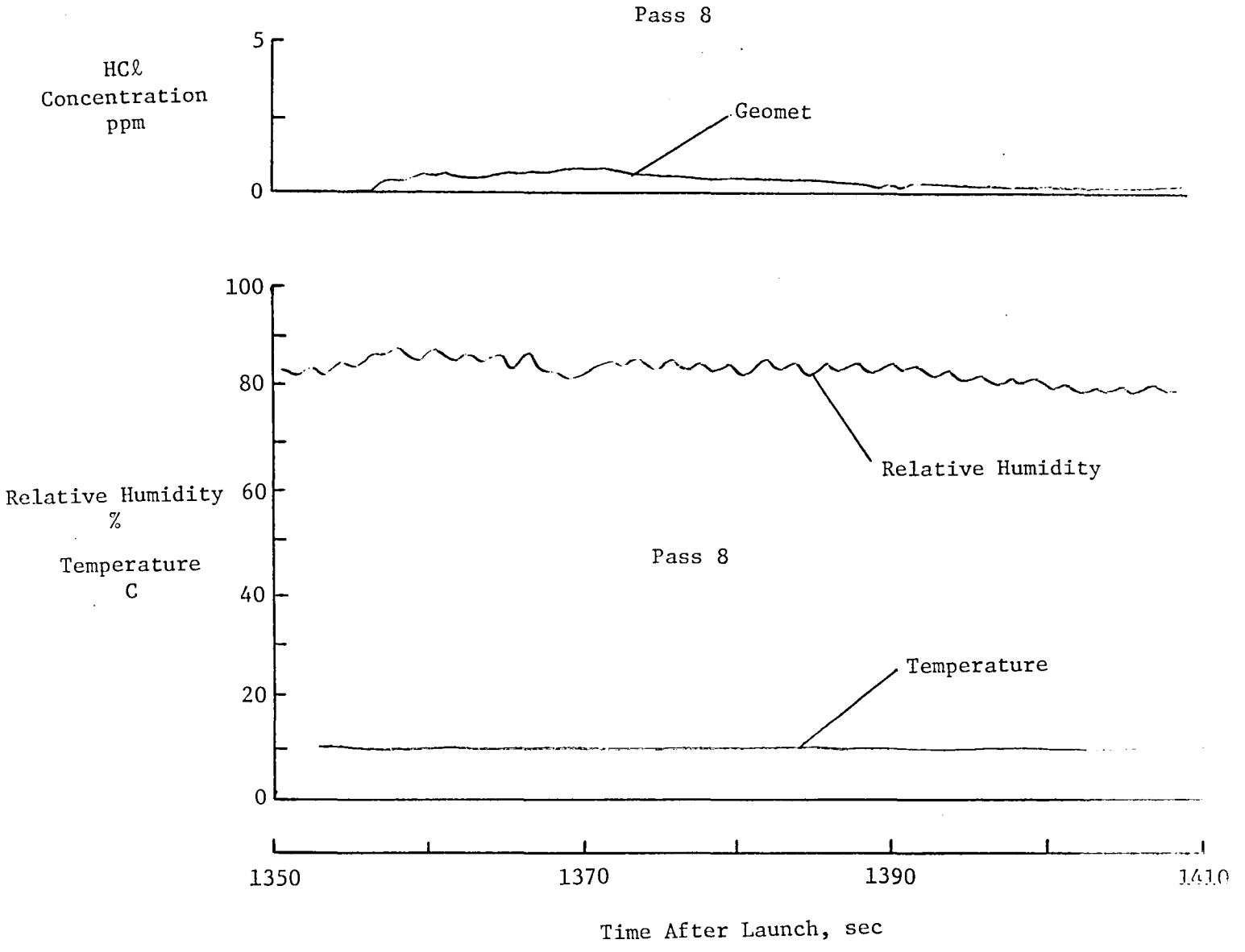


Figure 9.- Continued.

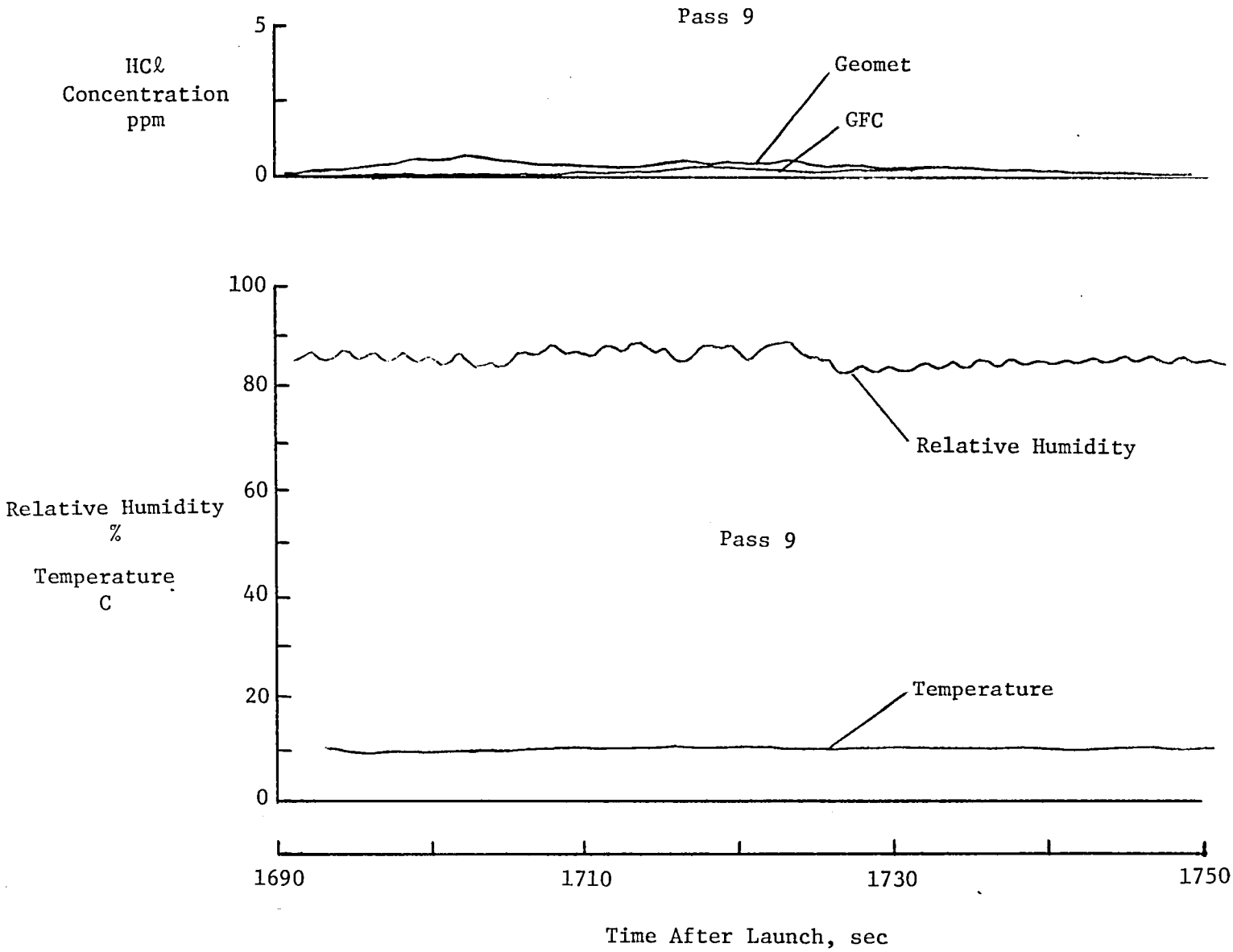


Figure 9.- Continued.

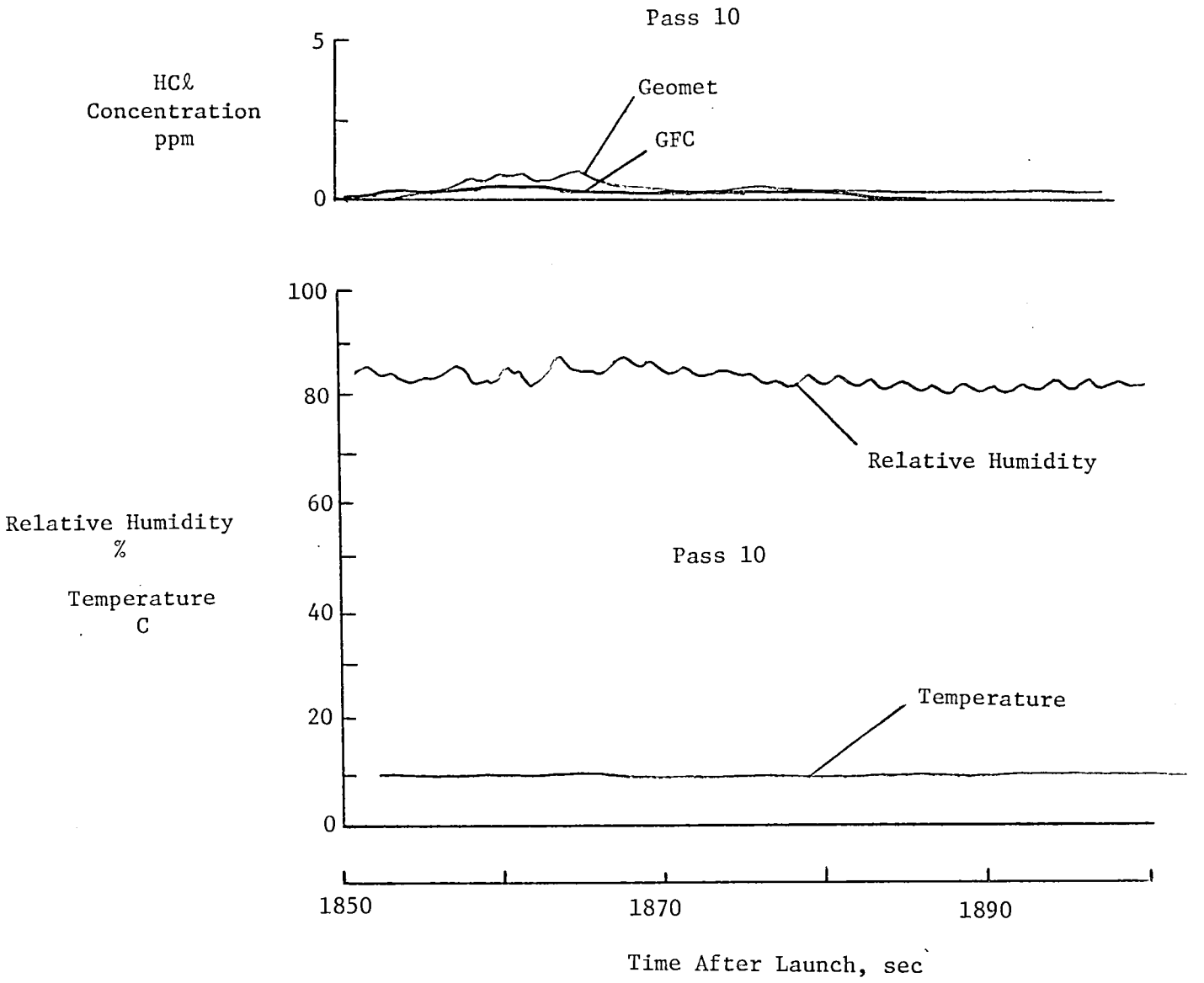


Figure 9.- Continued.

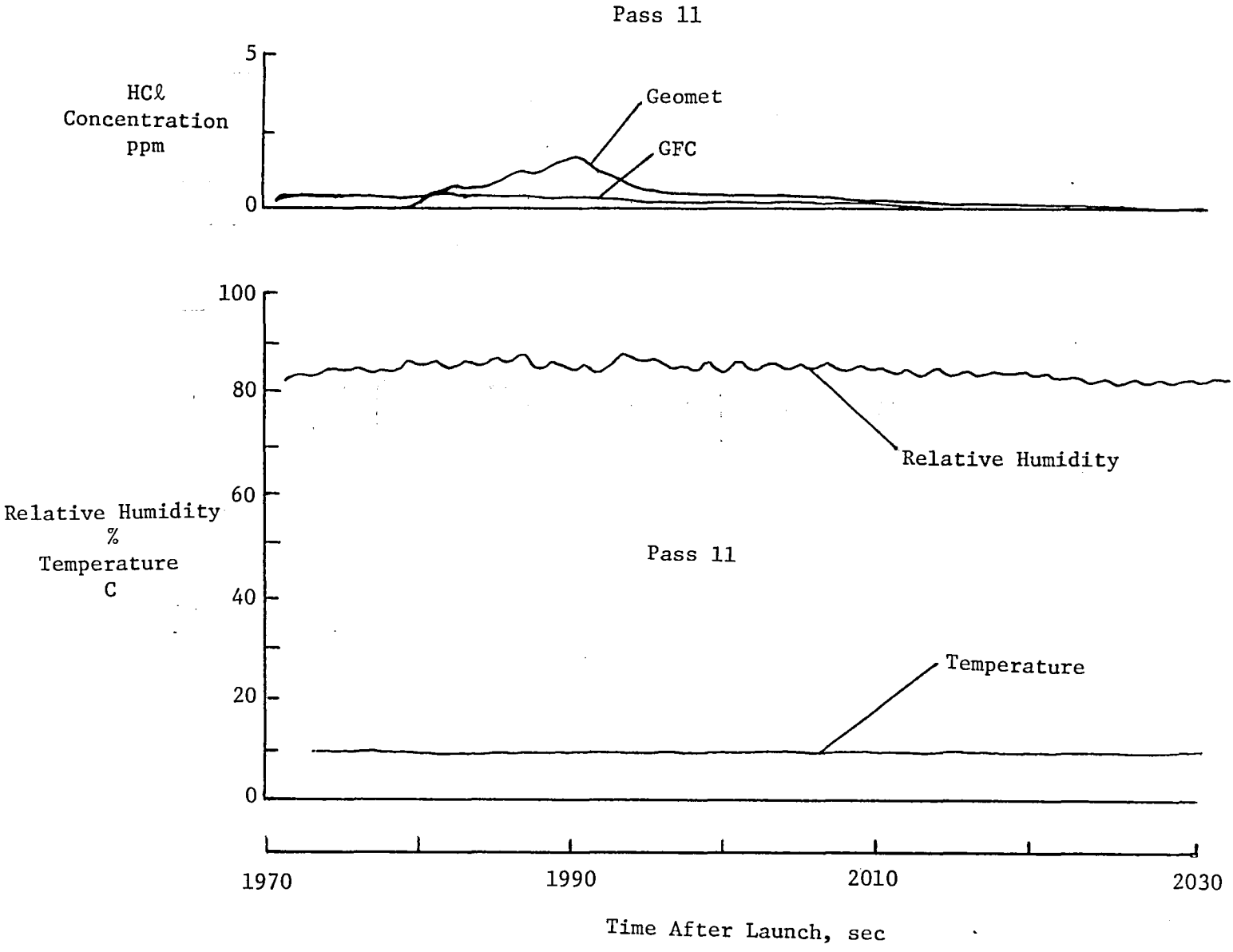


Figure 9.- Continued.

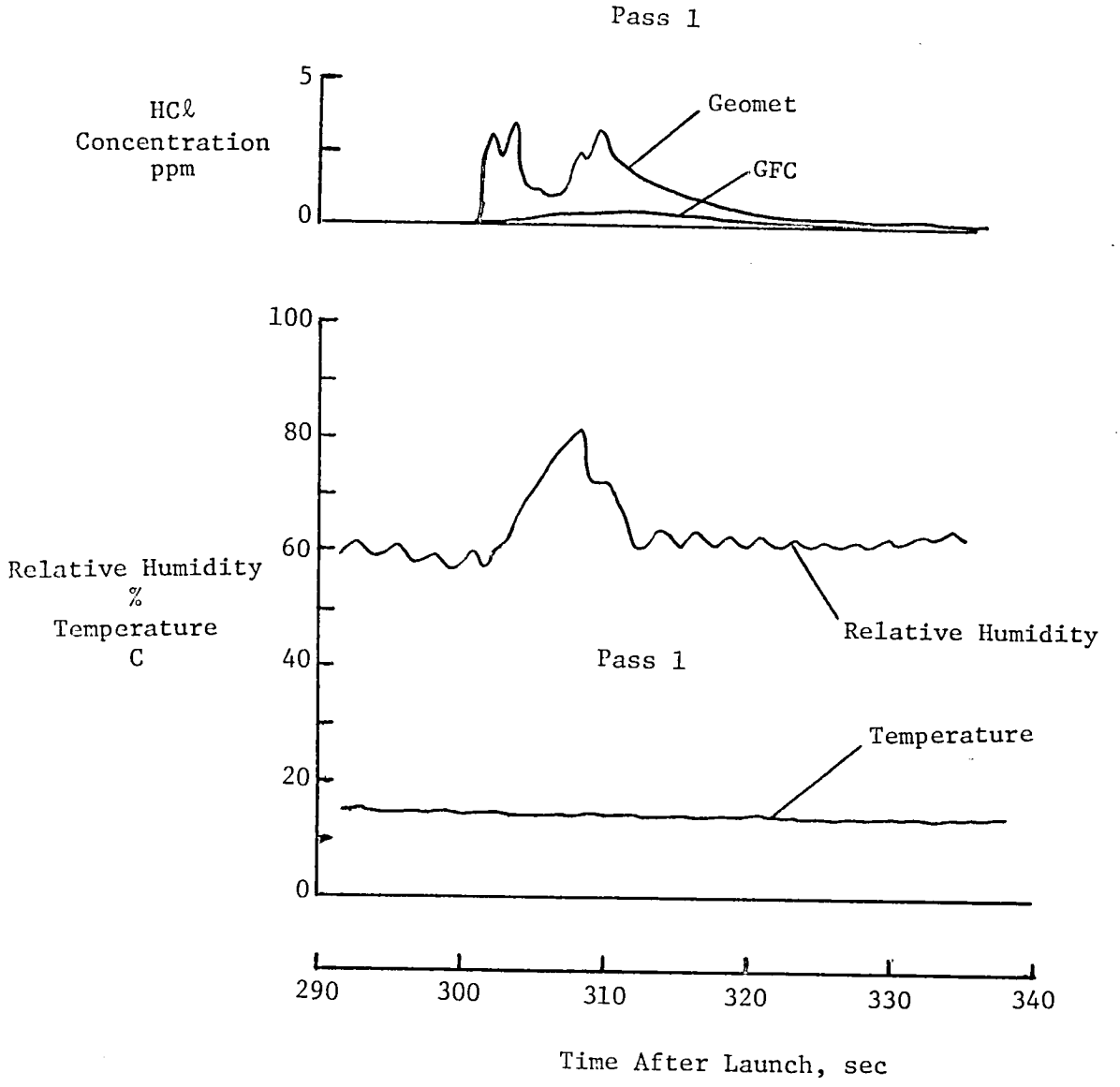


Figure 10.- Measured hydrogen chloride concentrations, relative humidity, and temperature obtained in-cloud with airborne sensors versus time after launch. November 21, 1979.

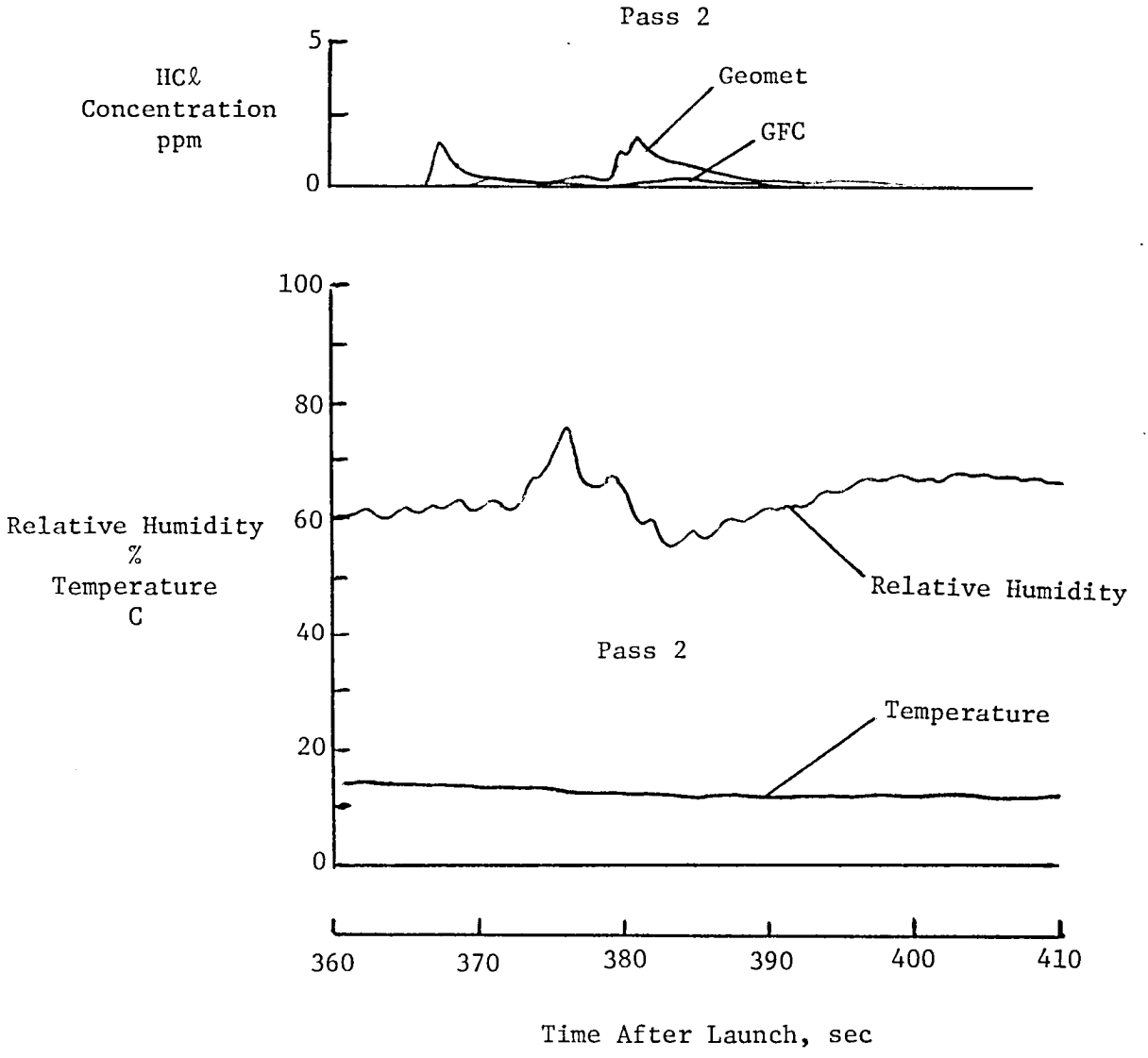


Figure 10.- Continued.

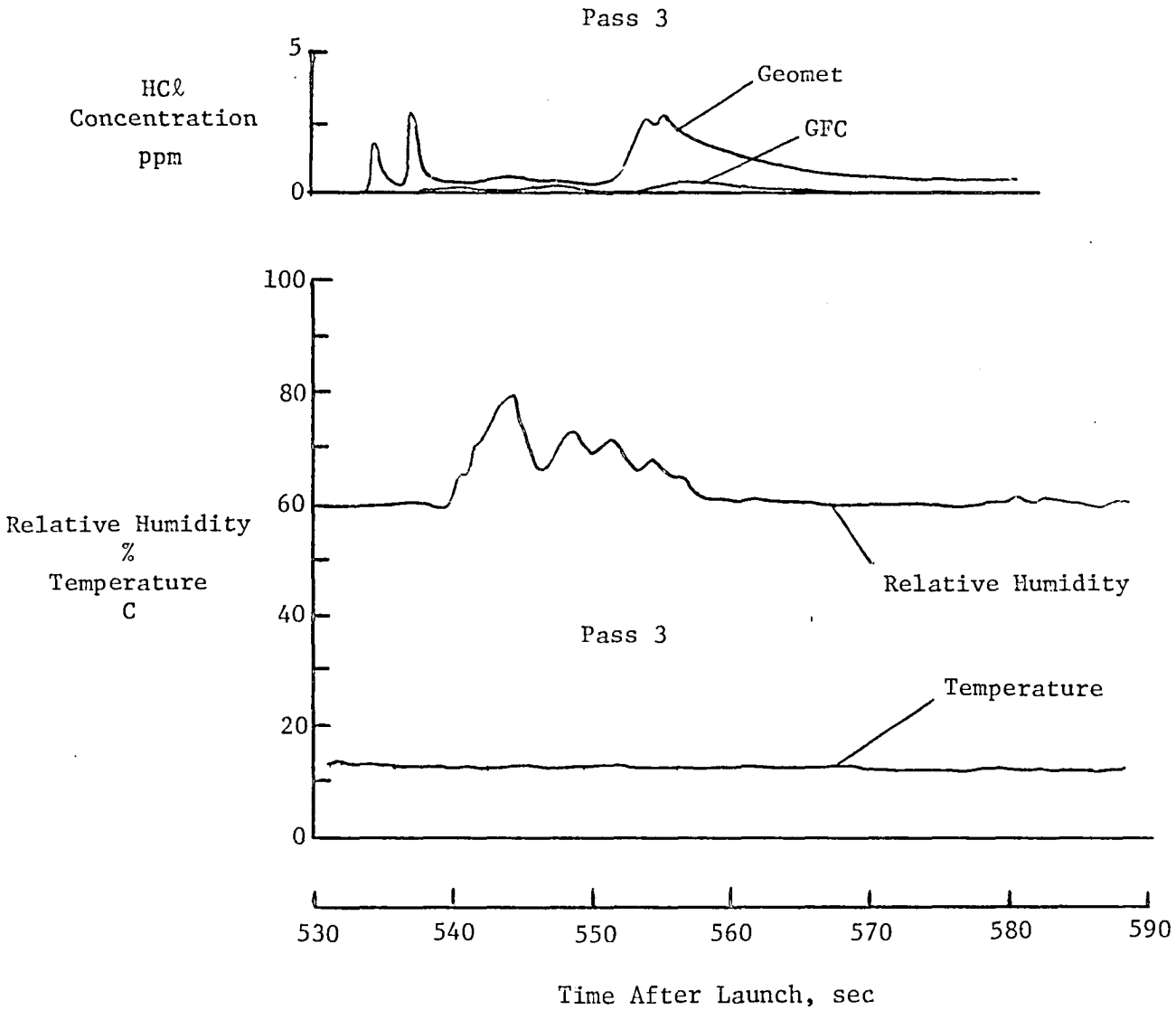


Figure 10.- Continued.

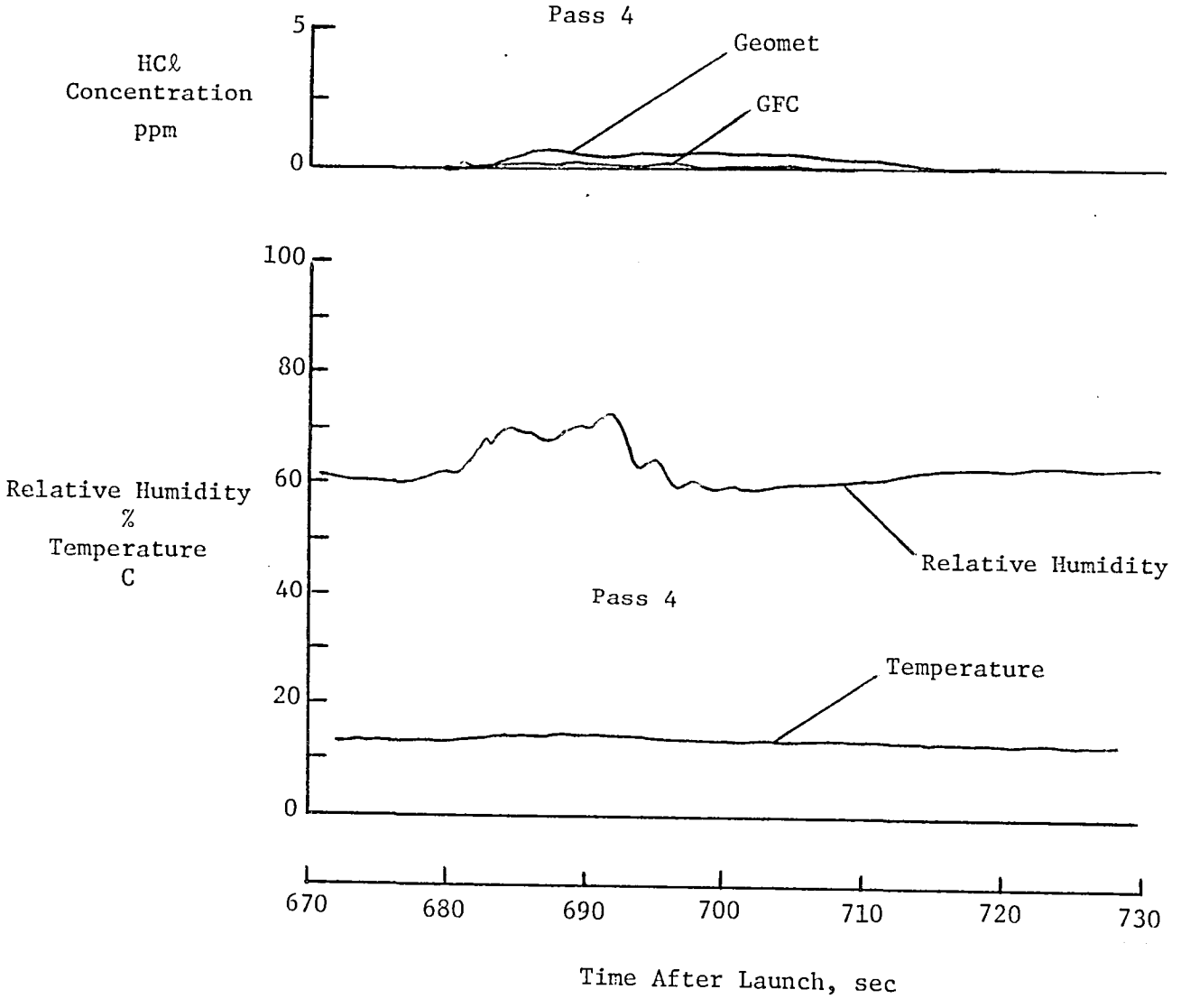


Figure 10.- Continued.

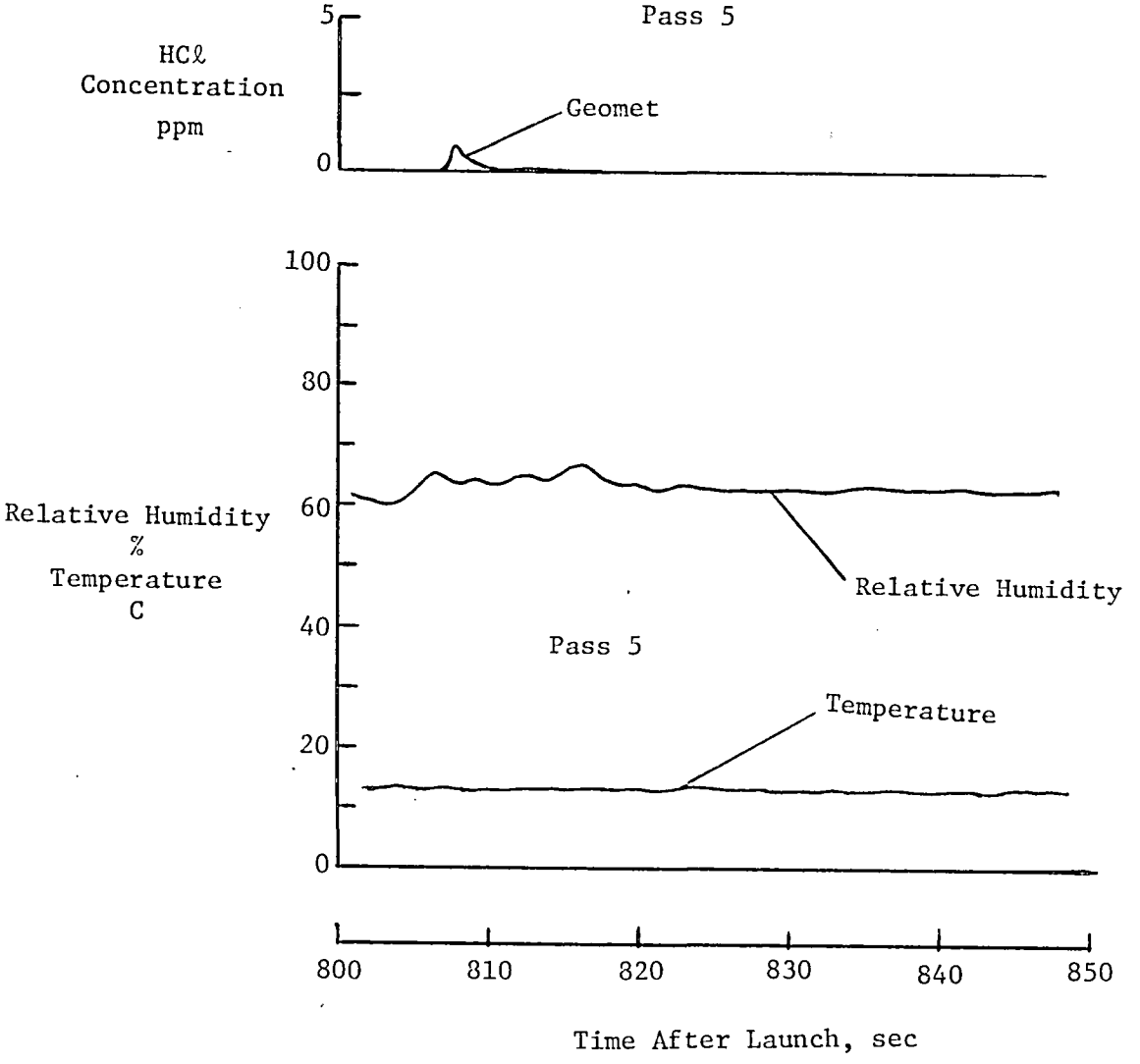


Figure 10.- Continued.

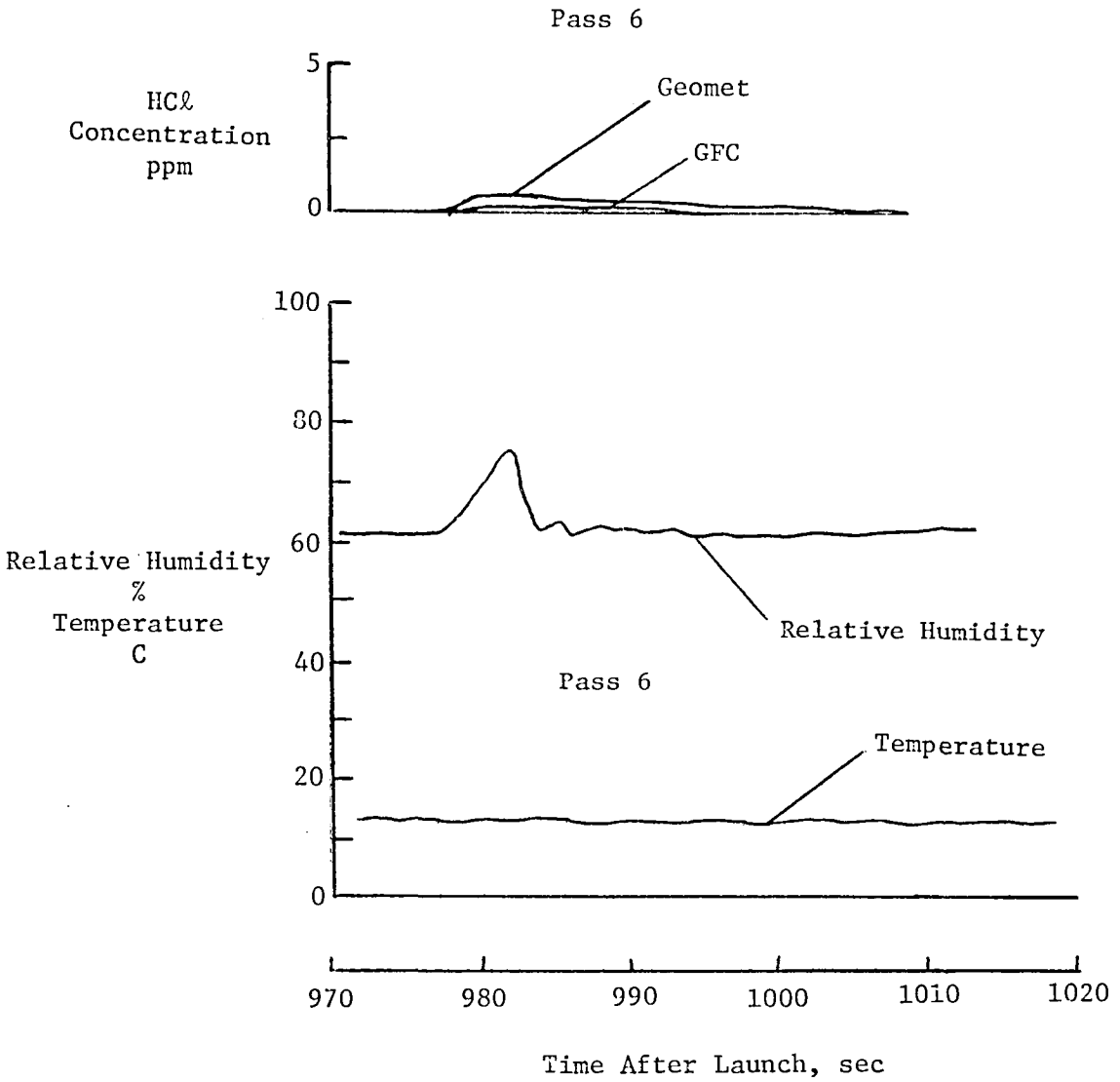


Figure 10.- Continued.

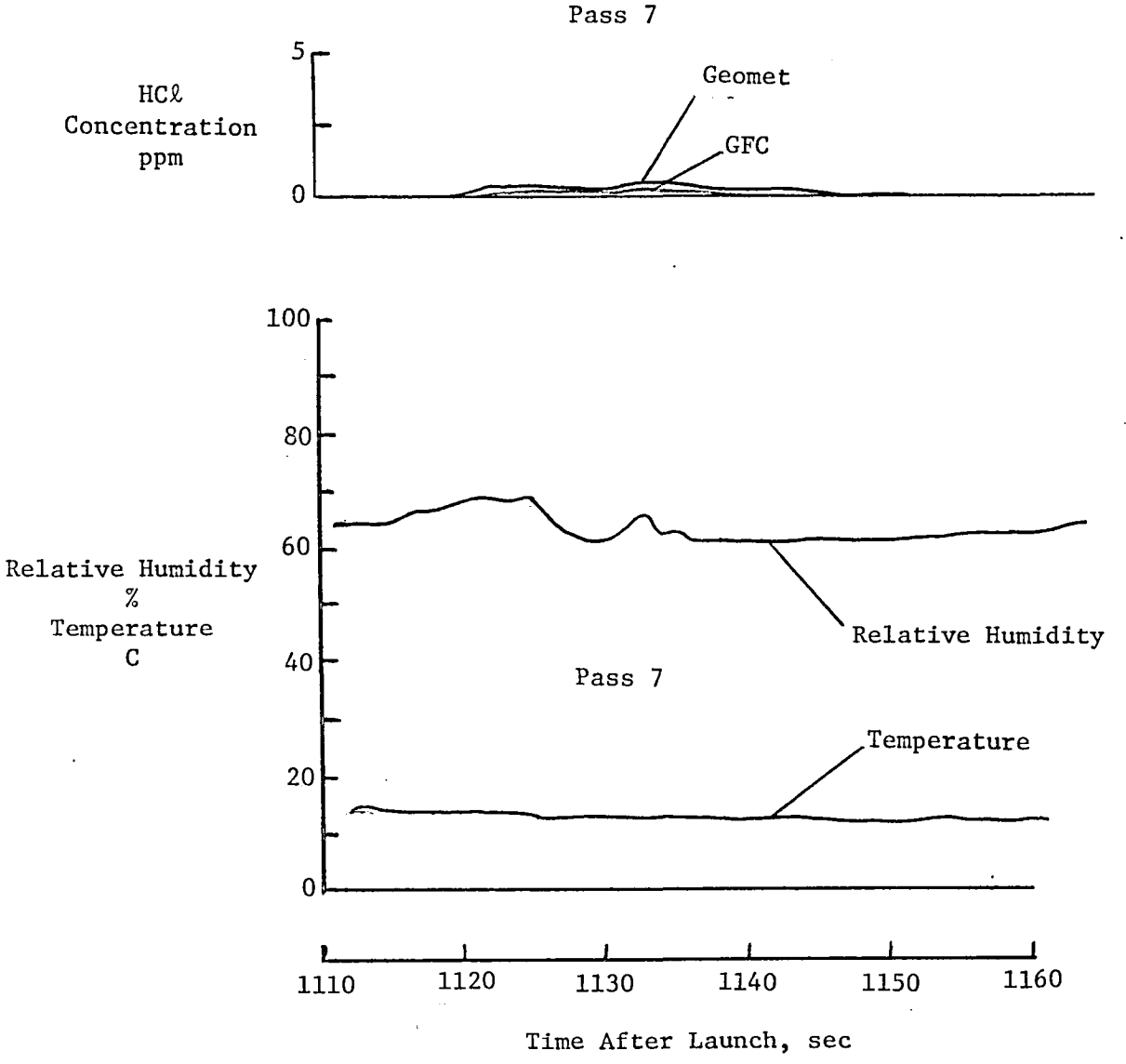


Figure 10.- Continued.

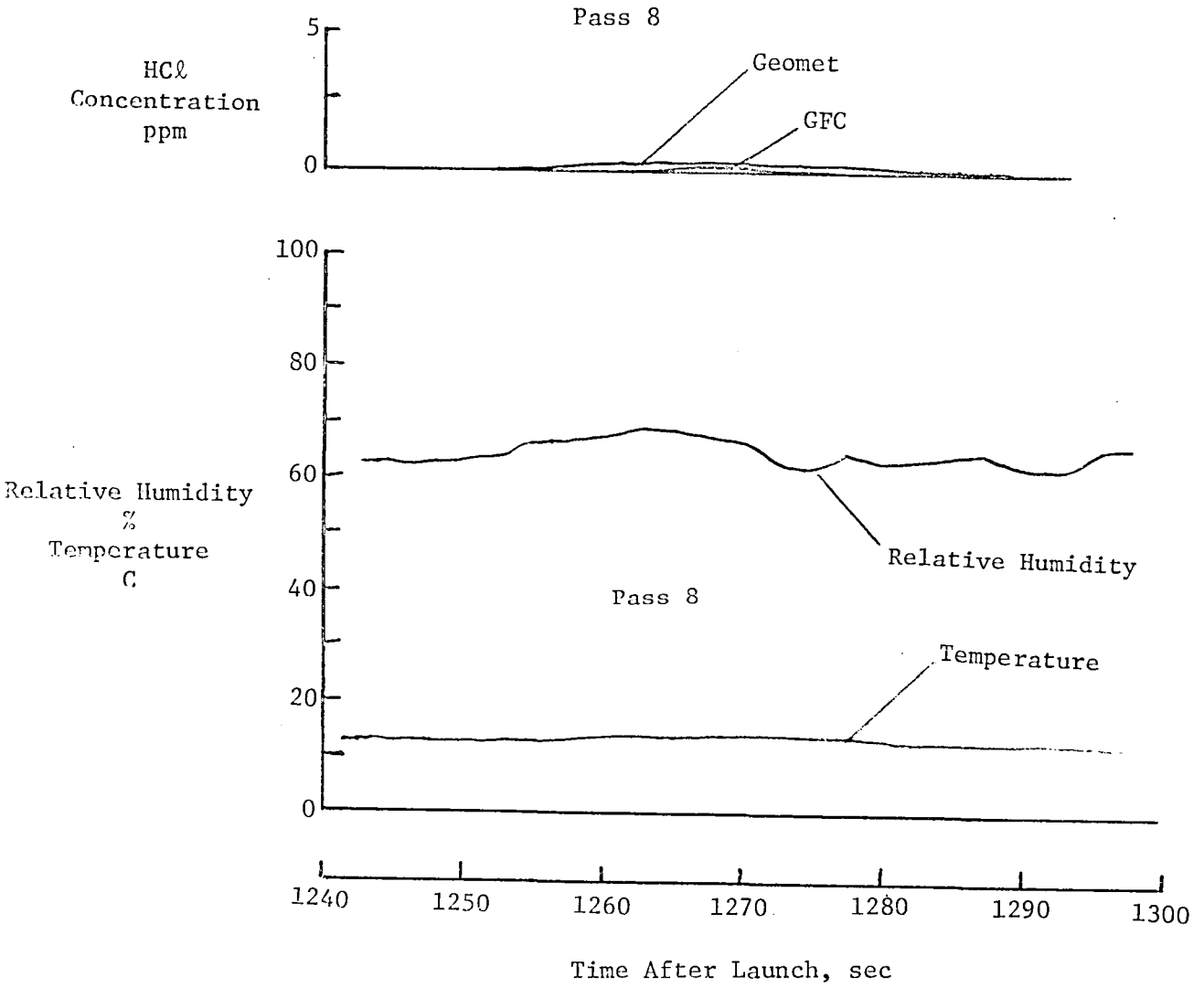


Figure 10.-Concluded

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-81830		

4. Title and Subtitle	5. Report Date
GROUND CLOUD HYDROGEN CHLORIDE MEASUREMENTS FROM THREE TITAN LAUNCHES AT THE KENNEDY SPACE CENTER DURING 1978 AND 1979	June 1980
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Daniel I. Sebacher, Robert B. Lee III, and Joseph J. Mathis	
	10. Work Unit No. 506-52-33-01
9. Performing Organization Name and Address	11. Contract or Grant No.
NASA Langley Research Center Hampton, Va. 23665	
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Memorandum
National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Total hydrogen chloride and gaseous hydrogen chloride concentrations were measured in the exhaust cloud produced at three Titan III launches at the Kennedy Space Center in March 1978, December 1978, and November 1979. The primary purpose of these measurements was to determine the degree of hydrogen chloride partitioning in a solid rocket exhaust cloud between gaseous hydrogen chloride and hydrochloric acid aerosol as a function of ambient relative humidity. Moderately low relative humidity conditions were present during a daytime launch on March 25, 1978, and high relative humidity conditions were present during a nighttime launch on December 13, 1978.

Total and gaseous hydrogen chloride concentrations and meteorological data, as a function of time after launch, are presented in this report. The measurements show that hydrogen chloride is present in both the gaseous and aerosol phase in the exhaust cloud. Total HCℓ concentrations ranged from 18 parts per million by volume (ppm) several minutes after launch down to 1 ppm after the cloud stabilization period, depending on the meteorological conditions. Gaseous HCℓ concentrations ranged from 2 to 3 ppm several minutes after launch to less than 1 ppm after cloud stabilization. These measured concentrations indicated significant HCℓ aerosol formation.

17. Key Words (Suggested by Author(s)) (STAR category underlined)	18. Distribution Statement
Effluent sampling Rocket vehicle exhaust Titan III exhaust effluents	Unclassified - Unlimited Subject Category 45

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	46	A03